Leading a Lean Transformation in the Wake of a Disaster

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Submitted to the Department of Mechanical Engineering and the Sloan School of Management in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
and
Master of Science in Mechanical Engineering

In Conjunction with the Leaders for Manufacturing Program at the
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Christian G. Caballero

Submitted to the Department of Mechanical Engineering and the Sloan School of Management on May 6, 2005 in partial fulfillment of the Requirements for the Degrees of Master of Science in Mechanical Engineering and Master of Business Administration

Abstract
Through a disaster, a company is presented with an opportunity to leverage the momentum from recovery efforts to drastically change the way business is conducted. In the case of Raytheon's Solid State Microwave division, the loss of its substrate fabrication facility due to a catastrophic fire prompted the company to create a closer, more integrated relationship with a local contract manufacturer. This more integrated relationship led to drastically reduced manufacturing cycle times and introduced Raytheon's Solid State Microwave division to a Just-In-Time relationship with a contract manufacturer. The more integrated relationship between the two companies also highlighted the potential labor savings associated with enabling operators to retrieve parts from small, satellite inventories (mini-markets) instead of using kits prepared by stock clerks in a centralized storeroom. It is hoped that Raytheon Solid State Microwave and Raytheon's Supply Chain Management division will apply these lessons to other suppliers as well as within Raytheon's own internal manufacturing sites.

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1 Introduction and Background Information

This thesis represents the results of work performed over the course of a six month internship at Raytheon Space and Airborne Systems, fulfilling the requirements of the Leaders for Manufacturing Program at MIT. The project was sponsored by Raytheon Space and Airborne Systems and was carried out in Raytheon's Solid State Microwave division in El Segundo, California. This project focused on the opportunity to use lean techniques to hasten recovery from a disaster and the ability to use a disaster as a vehicle for implementing far-reaching lean goals.

In the case of Raytheon's Solid State Microwave division, the loss of its substrate fabrication facility due to a catastrophic fire prompted the company to create a closer, more integrated relationship with Teledyne, a local contract manufacturer. This more integrated relationship led to drastically reduced manufacturing cycle times and introduced Raytheon's Solid State Microwave division to a Just-In-Time relationship with Teledyne. The more integrated relationship between the two companies also highlighted the potential labor savings associated with enabling operators to retrieve parts from small, satellite inventories (mini-markets) instead of using kits prepared by stock clerks in a centralized storeroom. It is hoped that Raytheon Solid State Microwave and Raytheon's Supply Chain Management division will apply these lessons to other suppliers as well as within Raytheon's own internal manufacturing sites.

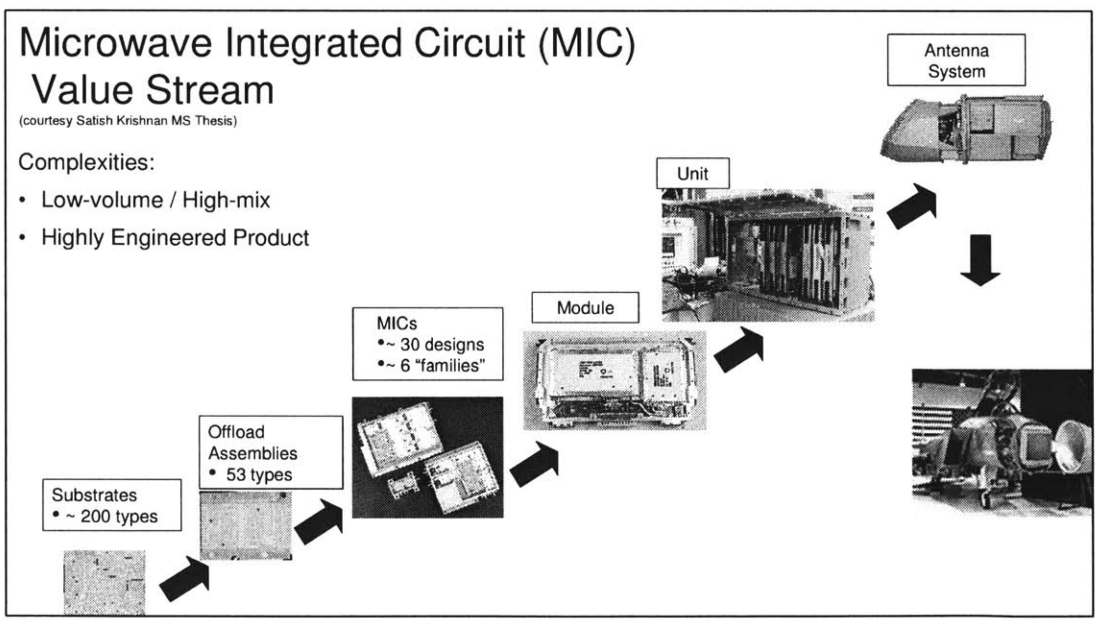
1.1 Raytheon Space and Airborne Systems Company Background

Raytheon's Space and Airborne Systems (SAS) division "provides electro-optic/infrared sensors, airborne radars, solid-state high energy lasers, precision guidance systems, electronic warfare systems, and space-qualified systems for civil and military applications. SAS is a leader in the design and development of integrated systems and solutions for advanced missions including: unmanned aerial operations, electronic warfare, active electronically scanned array radars, airborne processors, weapon grade lasers, missile defense, and intelligence, surveillance and reconnaissance systems.

SAS had 2004 net sales of $4.1 billion."[1] The division of Raytheon SAS specifically referenced in this thesis designs and manufacturers a variety of products including radar systems for military aircraft. SAS manufactures a variety of radar systems that range from 20 year old legacy systems to cutting edge "active array" systems. This El Segundo division has a fairly complicated history, beginning its life as Hughes Aircraft Company, a non-profit research center that was first acquired by General Motors. After a few years this El Segundo division was ultimately acquired by Raytheon.

SAS must meet the growing demand for their most advanced systems while continuing to provide sporadic replacement modules and technical support for a growing list of legacy systems. Given this diversity of demands and production rates, it is not surprising that SAS has a complicated mix of traditional batch-and-queue production systems and newer, lean production systems.

1.2 Product Flow



Substrates

Substrates provide the mechanical structure and electrical connections for radio frequency circuits. Approximately 200 unique substrates are used to build the various components manufactured in the Solid State Microwave factory. These two hundred substrates can be grouped into 20 families based on similarities of materials and production methods. Substrates were previously manufactured by Raytheon but, due to a fire, substrates are now purchased from outside vendors.

Offload Assemblies

Offload assemblies are comprised of substrate material and a metal housing that act as a structural base, electrical components (resistors, capacitors, etc.), and electrical interconnects. Between one and three substrates are used in the manufacture of each offload assembly. As connoted by the name, the bulk of the manufacturing of these assemblies has been offloaded to Teledyne, a local contract manufacturer. The substrates are attached to the metal carrier at Raytheon while the attachment of electrical components and wire bonding are performed at Teledyne. Because the manufacture of offload assemblies is shared, there are additional challenges in coordinating and standardizing work. Additionally, transportation time increases cycle time.

Microwave Integrated Circuits

Microwave Integrated Circuits (MIC's) are considered Solid State Microwave's final product. 30 varieties of MIC's, grouped into six general families, are currently produced in the same factory. MIC's are comprised of a metal housing that encloses a variety of substrates, electrical/RF components, and wire bonds. While MIC's may or may not contain offload assemblies, this thesis will deal only with the family of MIC's that does contain offload assemblies.

MIC's are assembled, functionally tested and tuned, hermetically sealed, and environmentally tested. MIC's that have passed testing are then shipped to internal and external customers.

Modules, Units, and Antenna Systems

Modules are comprised of a number of MIC's and electrical interconnects that are secured within a housing. These Modules are, in turn, integrated into Units. The Unit functions as the brains of an antenna system. The Unit ties together a number of modules with a self-contained computer system. These units are finally integrated into the antenna system, the functional product that allows a pilot to navigate the aircraft and track objects in the air and on the ground. Raytheon manufactures antenna systems for several types of military aircraft. These systems operate at different frequencies and differ in form factor. However, at a high level, all have functionally similar components and follow similar assembly and test processes.

2 Overview of Relevant Manufacturing Process, Prior to July 2004

2.1 Introduction

This chapter introduces the general manufacturing processes historically followed by Raytheon's Solid State Microwave (SSM) division and Teledyne, a local contract manufacturer, during the assembly of "offload assemblies." The manufacture of offload assemblies involves two major touch-labor steps: the assembly of 90-dash subassemblies and the final assembly of offload assemblies at Teledyne. While the Raytheon storeroom does not provide touch labor, the storeroom is an integral part of the manufacturing process. The historical responsibilities of the SSM storeroom are also introduced.

2.2 90-Dash Subassembly Manufacturing

The basic manufacturing flow for one family of MIC's begins with the manufacture of a "90-dash sub-to-carrier" assembly, or simply a "90-dash." A 90-dash subassembly is composed of one to three substrates that are attached to a metallic carrier (Figure 1). SSM manufactured 52 different varieties of 90-dash subassemblies.

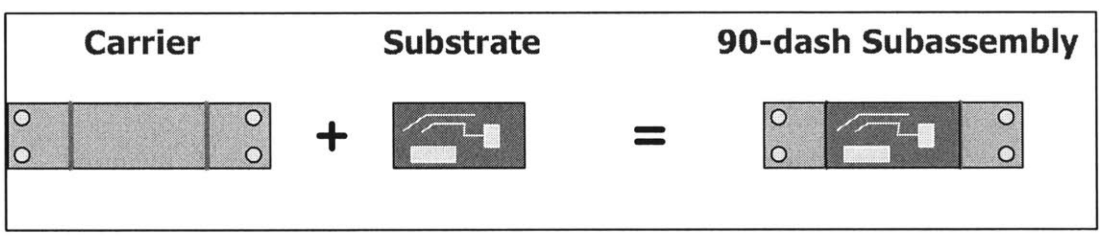


Figure 1: Simple Illustration of a 90-dash Subassembly

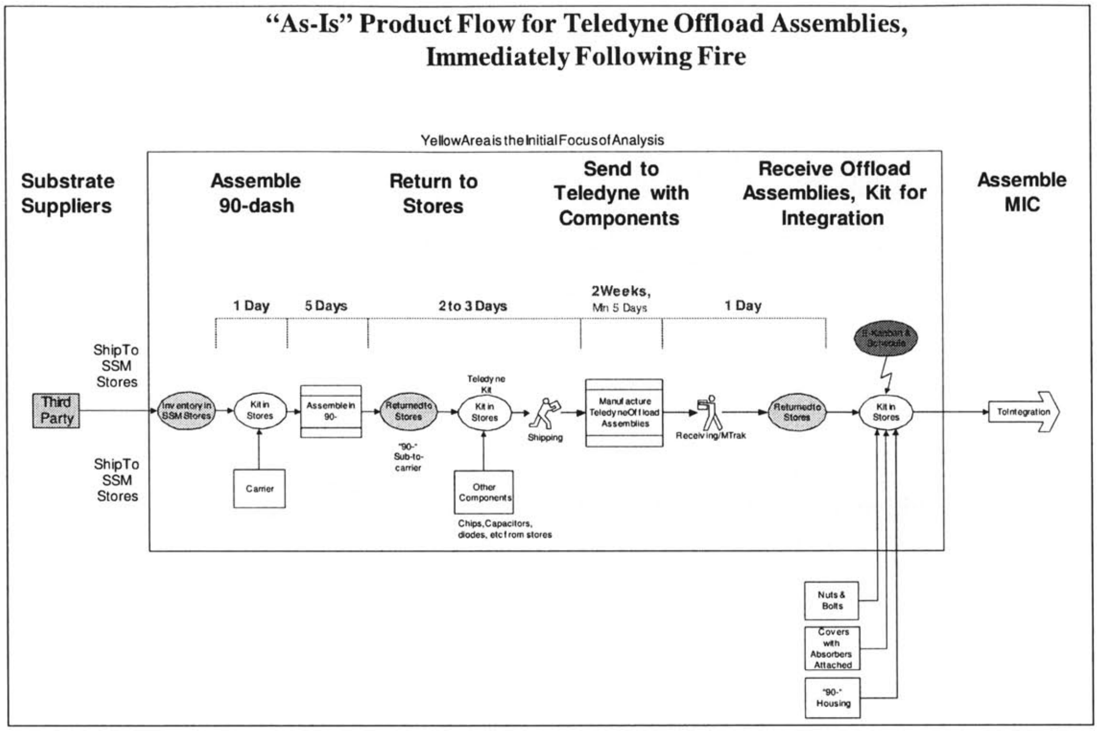


Figure 2: Product flow for offload assemblies

2.2.1 Parts Kitting

Substrates and carriers were kitted by clerks in the local SSM storeroom. These kits were prepared in lot sizes of five. The kitting of parts was triggered by Raytheon's MRP system.

Preparing a 90-dash kit in the storeroom was a relatively fast and easy task, requiring approximately 10 minutes of labor and data entry. The supervisor in the storeroom commented that she liked having a small stream of 90-dash kitting work because she could have clerks prepare 90-dash kits during work lulls.

2.2.2 90-dash Assembly

The attachment of the substrate(s) to a carrier is accomplished using either epoxy or solder. Epoxy attachment requires more manual touch labor and entails several hours of oven-curing and cooling time. Solder attachment requires less touch labor because solder is pre-formed to fit the shape of the substrate being attached to the carrier. Solder attachment entails approximately 20 to 50 minutes in a specialized machine.

While the difficulty and, consequently, the time to prepare a 90-dash assembly varied significantly, approximately 10 90-dash assemblies could normally be finished in 1.5 to 2.5 hours.

2.2.3 90-dash Priorities and Lot Sizing

The MRP system did not take into account the number of kits that were currently released to the production line. As a consequence, MRP would regularly flood the 90-dash assembly area with several weeks of work when production was perceived to be behind schedule. In practice the performance of various manufacturing areas was difficult to gauge consistently or accurately due to frequent changes to the master schedule that MRP based its calculations on.

Kits in the queue for the 90-dash assembly area were stored in nearby dry boxes. The kits were supposed to be arranged by the due date assigned by MRP, but the area was normally cluttered and out of order. Priorities were normally assigned to parts that were holding up the manufacturing line further downstream. These "hot" parts were then expedited.

Prior to the fire in SSM, all 90-dash assemblies were done in fairly large lot sizes. Due to non-trivial set-up times and the need to use scarce resources (specialized solder machine and a specialized curing oven), operators preferred to do large lots of a single type of 90-dash. These larger lots sizes allowed the operators to take advantage of economies of scale, specifically the ability to put up to 40 parts into a curing oven or 6 to 20 parts into the DAP machine (depending on the part type).

In order to build large lots of a single part type the operators often searched through the available kits in their work queue and gathered several small lots of the same part type. It was not uncommon for lots of 30 of the same part to be processed at the same time.

2.3 Offload Assembly at Teledyne

The second major step towards producing a MIC involves the population of 90-dash sub-to-carriers with electrical/RP components and wiring of these components.

2.3.1 Preparation of Teledyne Kits in the Raytheon Storeroom

A Teledyne kit was comprised of all the parts required to make either 7 or 11 of a specific type of offload assembly. A kit would normally contain 90-dash sub-to-carriers and any required electrical/RF components. Of the 53 offload assemblies manufactured by Teledyne, the "high" rate offload assemblies were kitted in lot sizes of 11 and "low" rate offload assemblies were kitted in lots of 7. All kitting labor was provided by clerks in the Raytheon SSM storeroom. The kitting of parts was triggered by Raytheon's MRP system.

The kitting process required approximately 30 minutes of touch labor per kit and was assigned a lead time of 3 days in the MRP master schedule. Kits could be expedited when there was a specific need.

2.3.2 Transportation of Parts & Kits between Raytheon and Teledyne

Kits prepared by Raytheon were shipped to Teledyne once daily. This trip was carried out by a Raytheon expeditor who drove to Teledyne with the kits and any other parts they needed. The expeditor would also pick up any finished offload assemblies available at Teledyne.

The expeditor was also available to make extra trips to Teledyne when there were especially hot parts that needed to be moved.

2.3.3 Manufacturing Process at Teledyne

Complete kits at Teledyne were assigned to one of five Teledyne operators who worked almost exclusively on Raytheon work. Kits were assigned to these operators by the floor supervisor.

Offload assemblies were assembled in two major manufacturing steps. First, the 90-dash sub-to-carriers were manually populated with die and other components. These populated assemblies were then cured in an oven. In the second manufacturing step wire bonds were added to provide electrical connectivity. This wire bonding was performed using both manual wire bond machines and automated, programmable wire bond machines. As of June, approximately a quarter of the 53 offload assemblies could be prepared in the automated wire bond machine. Programming new wire bond patterns into the automated machine was a slow process and was done whenever a technician had spare time.

Before offload assemblies were shipped to Raytheon, seven of the 53 different types of offload assemblies were functionally tested at Teledyne. Relatively few problems occurred historically with the other 46 types of offload assemblies, so they were not tested prior to shipping. The floor supervisor performed a final inspection on all parts before they left Teledyne.

2.3.4 Offload Assembly Priority Determination at Raytheon

Priorities within Raytheon for offload assemblies were largely determined by studying a number of program-specific status sheets created within Excel. These sheets visually presented the shortages in the various MIC's in work. Each of the 30 MIC's produced by SSM had an individual status sheet. These sheets were created and maintained by several coordinators who manually shaded the status sheets to indicated completion of component assemblies and made individual notes. To update a status sheet, the coordinators physically observed assemblies in production and performed queries in the MRP system as well as the Shop Floor Data Manager. Due to constant changes on the shop floor and human error, these status sheets were never entirely accurate.

Status and priorities for the offload assemblies in particular were largely determined using a "tab run," a dot-matrix printout automatically generated by the MRP system on Monday morning. This "tab run" was approximately 100 pages of paper and was out of date within minutes of its printing. Up to date inventory levels could only be found by entering queries into the cumbersome MRP terminal.

2.3.5 Priorities at Teledyne

Teledyne was normally flooded with 100+ kits with varying quantities of parts. Kits were often sent to Teledyne with varying lot sizes due to an irregular supply of 90-dash sub-to-carriers. These kits were stored in bins on racks near the Teledyne manufacturing area.

Raytheon seldom revealed its scheduled delivery needs and, instead, sent priority list of "hot" parts to Teledyne every few days. The priority list sometimes included desired quantities of certain offload assemblies, but sometimes it did not. The priority list often changed from one day to the next, forcing Teledyne to suspend assembly of partially finished parts in order to accommodate "hot" parts.

2.4 Tops Kitting at Raytheon

The third major step towards producing a MIC is the collection of all the subcomponents required to produce one complete MIC. This kitting process is carried out by clerks in Raytheon's SSM storeroom.

2.4.1 Parts Kitting

A "Tops Kit" is an electrostatic bag containing all the parts required to make a single MIC. This kit includes an outer housing, cover, mechanical and electrical components, and the required offload assemblies. The top kits are staged in ten dry boxes located next to the supervisor's desk in the storeroom. Each dry box is dedicated to one of the ten MICs that require offload assemblies. The tops kit staging area allowed anyone in the storeroom to instantly recognize shortages or overstocks of kits by simply glancing at the dry boxes.

The supervisor liked to keep a buffer of approximately five of each top kit (approximately one week of work) in order to ensure smooth flow. The clerks normally "pulled" all of theses top kits over the weekend in preparation for the upcoming week.

2.4.2 Top Kits Release to Assembly Line

For the past three to four years a pull system has been used to regulate the launch of top kits to the production floor. A CONWIP (CONstant Work In Process) system is used to pull kits to the floor based on shipments of MIC's and the total capacity of the production line. After a MIC has been completed and has passed all functional and environmental testing, an automatic email signal (e-kanban) is sent to the storeroom. When the storeroom receives this e-kanban, they first verify that a complete top kit is available for launch. The storeroom then verifies that the current launch schedule calls for the release of that specific type of top kit. If all of these requirements are satisfied, then the top kit is released to the nearby assembly area.

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3 Disaster and Early Recovery Efforts

3.1 Introduction

In early July of 2004, a major fire occurred in one of the manufacturing areas within the solid state microwave (SSM) factory. This area had been where the bulk of SSM processed its substrate materials. While the fire caused a great deal of damage, the bulk of the damage to the factory as a whole was due to water damage from the sprinkler system. When the fire was officially extinguished, the entire factory floor and a number of nearby offices were under one to seven inches of dirty water from the overhead sprinklers.

Following initial efforts to remove standing water, all products on the line (WIP) were collected for inspection and all testing and manufacturing hardware and tools were assessed for damage. Due to worries about mold growing inside the damp walls, the bottom two feet of all affected walls were removed and industrial dryers were used to remove any remaining moisture. After nearly two weeks of around-the-clock clean up and construction, bargaining unit employees were allowed back to work.

With the workers back and the production line re-starting, it was critical to assess the impact of the fire on product deliveries to customers and the re-sourcing of the hundreds of different substrates that SSM previously manufactured in-house. The issue of finding alternative suppliers of substrate materials was absolutely critical as all of the products manufactured by SSM require some type of substrate. A committee of project managers, supply chain representatives, and engineers was assembled to assess the capabilities of various substrate manufacturers from around the country.

Within a few weeks of beginning the search for substrate manufacturers, SSM identified three different substrate manufacturers with the technological capabilities to meet the needs of SSM. Each of these three manufacturers was selected to produce a certain segment of the substrates used by SSM. Due to technological limitations, few to none of the substrates could be supplied by more than one of these manufacturers.

Figure 3: Substrate manufacturing area following the fire

Although the fire completely destroyed all substrates that were in the affected room, production was able to continue for several weeks because of the amount of substrate material that was in inventory in the SSM storeroom. The remaining inventory of substrate material in the storeroom, however, was uneven, with an abundance of some substrate types and none of several substrate types. The substrate inventory remaining after the fire allowed production to continue, but allowed very few complete, final products to be delivered to customers.

With a spotty inventory of substrates, sporadic deliveries of substrates from new suppliers, and even less predictable quality level, management of the 90-dash production line was a difficult task. To understand the situation thoroughly the following tasks were performed:

1. Establish an accurate count of the substrates on hand
2. Match these substrates to the offload assemblies they were used in
3. Quantify the effects of the substrate shortages on downstream MIC production
4. Communicate with downstream customers to understand how SSM deliveries would impact their operations and deliveries
5. Create priorities for the substrate suppliers to fill the most critical holes first

Within a few weeks of the fire, Raytheon's substrate recovery team had preformed these tasks and provided the new substrate manufacturers with rational and achievable delivery goals.

3.2 First Week after the Production Line Resumed

The week following the restart of the production line was the first week back to work for the majority of the work force and the end of two very difficult weeks for most of the salaried employees. Most efforts were still focused on assessing damage to parts and hardware. Predictably, most of the returning workers were concerned about the effect of the fire on the factory and, specifically, their jobs. To stem unnecessary anxiety and rumors, the director of SSM operations held three all-hands meetings, one for each shift, to give his accounts of the damage, describe the vision for the future, and take questions. This speech was followed by more program-specific details from the SSM project managers. Following this meeting, every worker in the department understood that there was going to be a lot of hard work in the coming weeks and months.

The first week also marked a major shift in the focus of the internship project. Until the time of the fire the project and research primarily dealt with lean efforts within the SSM storeroom. Production projections indicated that it would be much more valuable for someone to restructure the strategic relationship between Raytheon and Teledyne.

Based on the inventory available, expected deliveries of substrate material from new suppliers, and the historical average cycle times for manufacturing offload assemblies it was determined that SSM would miss several critical delivery dates within two months. Worse yet, it was determined that these projected delivery misses would cause the downstream customer's production line (another division of Raytheon) to shut down, leading to the furlough of several operators.

With new production priorities, it suddenly became essential that SSM streamline its production of offload assemblies by collapsing the total cycle time from approximately 20-60 days to approximately one week.

3.3 Manual Management of 90-dash and Offload Assembly Priorities

3.3.1 Overview of "Usable Inventory"

One of the most important and overlooked measures of the value of inventory in a high-mix/low-volume manufacturing environment is "Usable Inventory." Usable inventory is simply the portion of current inventory that can be used to produce a complete product. In Figure 4 is a diagram of a fictitious microwave integrated circuit (MIC) that utilizes four unique offload assemblies in addition to a number of miscellaneous components and a housing. Given the previous definition of usable inventory, inventory of the four different offloads would only be "usable" if there was inventory of all four. Further, the total level of usable inventory would be limited by the offload assembly with the fewest parts in stock. As shown in Figure 5, if Raytheon had in stock 25 of Offload #1, 53 of Offload #2, 6 of Offload #3 and 33 of Offload #4, then only six of each Offload assembly would be "usable." Further, if there were any stock-outs of an offload assemblies, any inventory of the other offload assemblies used in the same MIC would be 100% unusable.

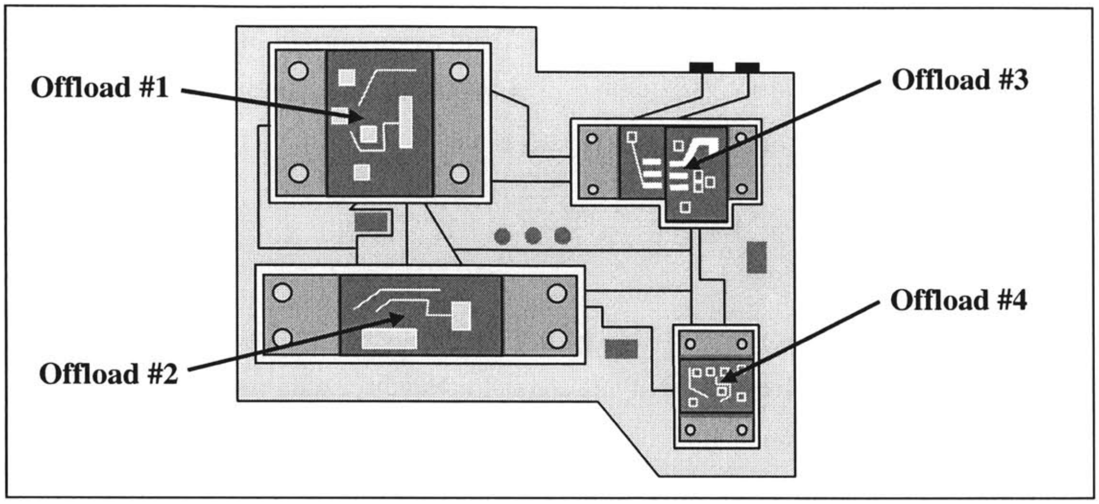

Figure 4: Fictitious MIC and required offload assemblies

Part Description	Total Inventory	Usable Inventory	Un-usable Inventory
Offload #1	25	6	19
Offload #2	53	6	47
Offload #3	6	6	0
Offload #4	33	6	27
Totals:	**117**	**24**	**93**
Only 21% of Total Inventory is "usable"			

Figure 5: Example calculation of "Usable Inventory"

One of the main goals during recovery was to maximize the amount of usable inventory so as to minimize the number of MICs that would be built short. Short builds always introduce unnecessary complexity and clutter (unworkable WIP) to a manufacturing process. It was therefore critical to minimize the number short-builds.

Solid State Microwave had historically had difficulty maintaining usable inventory. Large inventories of several offload assemblies were often rendered unusable due to stock-outs of one or two other offload assemblies used in the same MIC. For example, on

August 8, 2004, only 11, or **1.2%, of the 945 offload assemblies in inventory were "usable."** By August 25, 2004 the percentage of usable inventory improved to 24%, with 127 usable offload assemblies out of 530 in stock.

3.3.2 Teledyne Priorities

Much of July and August were spent learning about the then-current manufacturing flows in the 90-dash assembly area, at Teledyne, and in the Raytheon storeroom. Before the end of July the author had assumed the role of primary Raytheon contact to Teledyne. As the primary point of contact to Teledyne the author was responsible for communicating Raytheon's priorities to Teledyne.

> *"Finite scheduling is hard work. It requires accurate and timely labor reporting; carefully constructed routings; properly defined work centers; and realistic work center structure. It is very unforgiving of imprecise information, sloppy operation, or weak administration. It requires monitoring and intervention by schedulers and planners."* [2]

In order to get a grasp Raytheon's true needs, it was necessary to do the following (similar to steps taken by SSM to determine substrate priorities for the new vendors):

1. Establish an accurate count of offload assemblies and MIC's in inventory and WIP
2. Determine the desired production rate for each MIC
3. Use the MIC production rates to determine desired production rate for the 53 offload assemblies
4. Create priorities for Teledyne to fill the most critical holes first

Prior to July, 2004, the majority of manufacturing priorities given to Teledyne were fairly informal, lacked specific quantities required, and changed frequently. My initial goal was to provide Teledyne with as much information as possible regarding Raytheon's shortterm requirements as well as a projection of future demands. This type of information was critical for Teledyne to use in making staffing decisions.

An early estimate of Teledyne deliveries needed to meet Raytheon's recovery schedule showed that throughput needed to double for at least three months. By presenting information on the upcoming need to surge in production, Teledyne was able to bring several operators with the required skills from other areas.

A successful step towards providing timely forecast information was the creation of a weekly priority sheet for Teledyne. This weekly Priority Sheet (Appendix A) featured forecasts for each of the 53 offload assemblies for three to five weeks. It was agreed that the priority sheet would be published every Monday and would not change for at least a week. The first two week of forecasted priorities were often referred to as "ice" to convey the fact that these priorities would not change. The third and fourth weeks were referred to as "slush" to express that these priorities were fairly certain but could change. Priorities more than five weeks out were referred to as "water" because they would likely change.

While these weekly priority lists were helpful, they were extremely time consuming to maintain due to the difficulty of gathering accurate inventory level information. Unless a new system was implemented or a full-time project manager took over responsibility for maintaining this document, the system would fall apart and return to one that was only driven by emergencies.

3.3.3 Variable vs. Fixed Time in 90-dash Assembly

One of the most compelling reasons for performing batch-and-queue operations was to amortize the fixed set-up time and costs over a large quantity of parts. Optimal lot sizes are often determined by balancing the benefits resulting from economies of scale with the associated increase in costs due to increased inventory and the reduction in manufacturing flexibility. In order to make an educated analysis of the 90-dash assembly process, it was necessary to understand the value of economies of scale as well as the negative effects of large 90-dash lot sizes on product flow.

> "Batch manufacturing fosters disconnected islands of value-added activity surrounded by moats of non-value-added events. Lean manufacturing blends value-added activities into a continuous-flow process while systematically eliminating non-value added events." [3]

A handful of time studies were performed immediately following the fire. These studies were intended to locate the effective bottleneck in manufacturing of offload assemblies. These studies of the 90-dash assembly process revealed that, despite the obvious fixed time required in the specialized solder machine and curing oven, the total cycle time became dominated by variable preparation time in lot sizes of eight or more.

<u>Solder</u>

The specialized solder machine required specific fixtures to hold the carriers and substrates during the soldering process. Most of these fixtures only had enough openings to accommodate 10 90-dash assemblies at one time. As a consequence of this constraint, lot sizes of 11 or more required the operator to load the specialized solder machine at least twice, thus reducing economies of scale.

Approximately 25% of the total cycle time is due to variable labor (directly dependent on the lot size) and the remaining 75% of the cycle time was fixed and independent of the lot size. Despite the percentage of fixed labor time, there was little motivation to prepare soldered 90-dash parts in lot sizes greater than eight. Lot sizes greater than eight would destroy the economies of scale by requiring the operator to load the specialized solder machine multiple times.

<u>Epoxy</u>

Unlike the soldered parts, 30 to 40 epoxied parts could be placed in the curing oven at once. However, the 90-dash parts secured with epoxy required significantly more touch labor time per part. For example, approximately 75% of the total touch labor required to manufacture 15 90-dash parts varied directly with the quantity of parts. Only 25% of the cycle time was fixed and independent of the lot size.

Despite the advantage of putting many epoxied 90-dash parts into the curing oven at the same time there was still little motivation to prepare these parts in large lots, i.e. larger than 8. The epoxy process is dominated by variable labor and the area is in a high-mix low volume setting – both of these factors favor smaller lot sizes.

3.3.4 90-dash Lot Sizes and Priorities

The initial study of 90-dash lot sizing and priorities discussed above revealed:

- The 90-dash assembly area was normally flooded with kits of parts, making it difficult to determine priorities
- It was common for operators to search the queue of work and collect kits of the same type into one large lot
- Although it was believed that these larger lots of parts were more efficient to process due to economies of scale, the savings were minor and virtually disappeared with quantities greater than 8
- It was not uncommon for operators to work on the easiest assemblies before working on more difficult or time-consuming parts
- Two operators, one working on first shift and the other working second shift, could provide more than enough capacity to meet normal or increased "recovery" demand

Subsequent to these discoveries, the flow of work into the 90-dash assembly area was modified. The following changes were made:

- 90-dash lot sizes were set to eight parts
- The amount of WIP in queue in the 90-dash area was limited to approximately 30 pieces, roughly the equivalent of one day of work

Note: One day of work was an ad-hoc decision made on the floor. This amount of work was chosen primarily because it is a simple quantity to track. Additionally, the reduction in the size of the 90-dash work queue prevents the 90-dash operators from "cherry-picking" only the easiest 90-dash kits or batching like parts into un-economically large batches. As a result of its success, this decision to limit the amount of WIP in the 90-dash area has become standard practice.

- 90-dash kits were released to the 90-dash assembly area according to a detailed release schedule designed to maximize the mix of parts produced

3.3.5 Results

With a greater number of smaller lots of parts, the 90-dash assembly area performed better than expected. After 90-dash lot sizes were reduced and first-in-first-out (FIFO) processing was enforced, 90-dash assemblies ceased to pace the flow of offload assemblies. It became clear that 90-dash assembly was not a bottleneck in the manufacturing flow.

During the recovery period in Solid State Microwave, the manufacture of offload assemblies at Teledyne was much more closely monitored and timely priority lists helped Teledyne to focus their energy on critical assemblies. By demanding specific quantities of these critical assemblies from Teledyne and focusing on maintaining product mix, much of the previously un-usable inventory at Raytheon was made usable. As was shown in the example given in section 3.3.1, Raytheon was able rapidly transform its inventory, nearly halving its inventory of offload assemblies from 945 to 530 while also increasing the fraction of usable inventory from 1.2% to 24%.

By increasing the proportion of "usable inventory" through decreased lot sizes and timely priorities, Solid State Microwave was able to dramatically increase its throughput of MICs during recovery and meet its promised delivery dates. These successful deliveries prevented Raytheon's customer from running out of work and thus allowed this customer to avoid a work furlough.

4 Creation of a Remote Inventory at Teledyne

4.1 Introduction

This chapter deals with the initial motivation for splitting the movement of parts from Raytheon to Teledyne into two distinct flows. The first flow, referred to as "bulk parts" or "bulk kitting," is the movement of purchased parts from Raytheon to Teledyne in monthly "bulk kits." The second flow is the daily movement of 90-dash subassemblies from Raytheon, where these subassemblies are manufactured, to Teledyne. At Teledyne these 90-dash subassemblies are then populated with Raytheon-supplied, purchased electrical components to create an "offload assembly." It will be shown that treating high-value parts differently than low-value parts can prevent unnecessary labor. It will also be demonstrated that, given appropriate tools, it is more efficient for an operator to kit his or her own parts from a local inventory than for an independent stock clerk to create a kit of parts in a central storeroom.

4.2 Inventory Analysis

> *"Inventories of different classes of parts should be treated differently."* [4]

4.2.1 Background Theory for Distribution by Value (DBV) Analysis

Hopp and Spearman offer an enlightening analysis of product inventories that compares the relative volume of parts consumed (percentage of total components consumed per year) to the aggregate value of these parts (Cumulative percentage of total annual cost volume).[4] The analysis normally yields three part categories: A-parts, B-parts, and C-parts.

A-parts are high cost-volume parts that are often either high-cost per part or low-cost per part but used in large volumes. A-parts normally account for only 10% of the total part varieties, but usually represent approximately 80% of the total dollar-value of the parts consumed. A-parts should be tracked carefully due to their small numbers and disproportionate impact on costs and inventory carrying costs. Because the A-part volumes are often high it is usually possible to take advantage of the economies of scale associated with these higher volumes. Suppliers should be willing to guarantee a high service level (minimal variability for delivery dates) for these few high-value, high-volume parts. Given the relatively value of A-parts, an increased service level for A-parts leads to dramatically lower inventory carrying costs.

B-parts are used in moderate volumes, normally responsible for 40% of the total volume of parts consumed and usually representing approximately 18% of the total dollar-value of the parts consumed. B-parts are normally stocked at moderate levels due to their moderate impacts on costs.

C-parts are low-value, low volume parts that normally account for around 50% of the total number of parts consumed but usually only represent approximately 2% of the total dollar-value of the parts consumed. It is recommended that C-parts receive minimal tracking and be stocked at higher levels. Maintaining a higher safety stock of C-parts helps to avoid stock-outs at a relatively low carrying cost.

This type of analysis can assist a company in defining an appropriate stocking level strategy. The intuition behind this stocking strategy is that a company should hold a larger reserve of low-value, low-volume parts to ensure greater parts availability at a minimal impact to the overall inventory value.

4.2.2 DBV Analysis to Illustrate Relative Costs of Part Families

The traditional method for representing the relative costs of different parts in a DBV analysis is through the use of a Pareto chart.[5] Such a Pareto chart clearly illustrates the relative contribution of each part to costs and, therefore, inventory carrying costs. The Pareto chart in Figure 6 clearly shows that 90-dash subassemblies and a small number of purchased parts and responsible for nearly 90% of the total part costs for offload assemblies.

Because 90-dash subassemblies are manufactured in-house by Raytheon and because of the high percentage of total part costs concentrated in 90-dash subassemblies, it is logical to treat 90-dash subassemblies differently than purchased parts. This basic conclusion was the main motivation for separating the flows of 90-dash subassemblies and purchased parts to Teledyne.

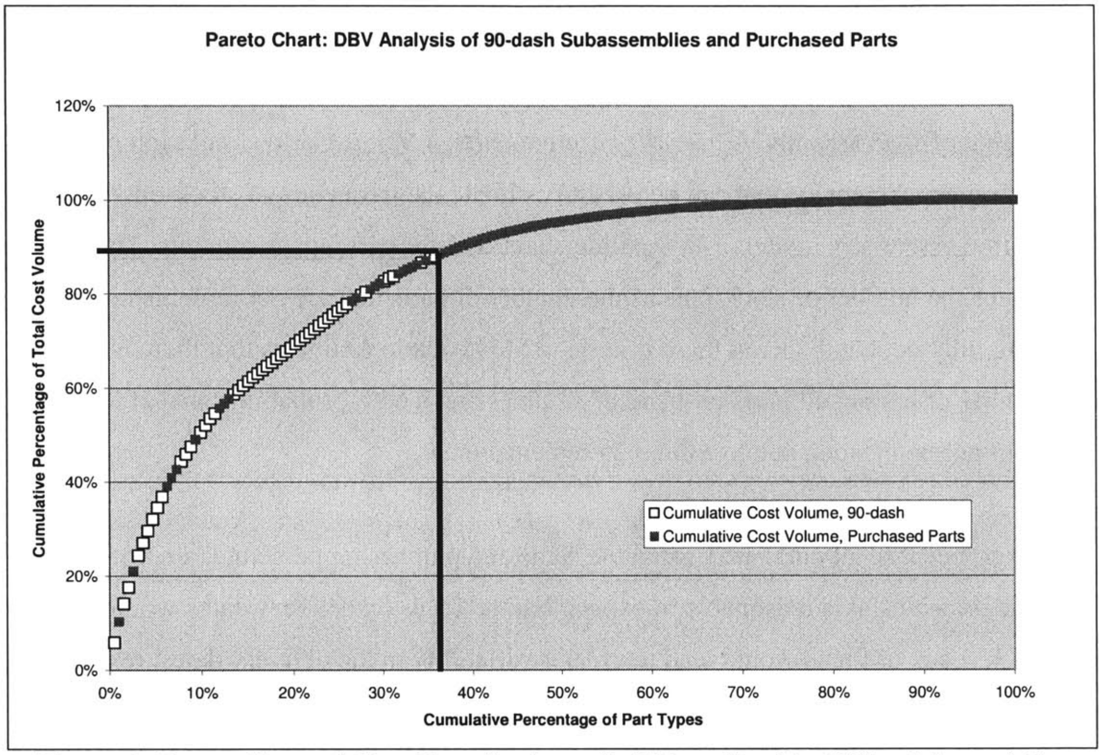

Figure 6: Pareto Chart of Cost Contributions of all Parts Used in Offload Assemblies

4.2.3 DBV Analysis used to Maximize Service Levels and Minimize Inventory Carrying Costs

4.2.3.1 Modeling Raytheon's Historical Inventory Stocking

As of the time of this project, the inventory management system used by Raytheon SAS in the El Segundo campus essentially treated each purchased part identically. The cost volumes for parts are not factored into the prescribed stocking level for each part. This strategy of treating all parts identically can be illustrated by an example. Assume that

Raytheon purchases 1.5 month's worth of a part when the inventory level for that part drops below 1.5 month's worth. In other words, if a part is consumed at the rate of 100 pieces per month, then Raytheon would order 150 more pieces whenever the on-hand inventory of the part dropped below 150 pieces. You can further assume that the lead time for receiving a part replenishment is 28 days with a normal standard deviation of 7 days. In other words, once an order for another 1.5 months of a part is placed, the parts are expected to arrive in 28 days with a certain degree of uncertainty.

Given that offload assemblies use 143 different parts, a Monte Carlo simulation of this type of replenishment system can be used to estimate the frequency of stock-outs. The simulation essentially models 143 separate lead times for part replenishments. The model calculates the number of stock-outs as the number of parts that are not replenished prior to being fully depleted. Given these criteria, a Monte Carlo estimates that there is a 33% probability of having all parts on-hand at all times and a 66% probability that at least one part will not be in stock due to a delay in replenishment.

However, because all parts are treated the same and purchasing personnel are not given specific priorities, it is reasonable to expect that the focus on delivery dates would diminish. Lack of focus would lead to greater variability in the delivery dates, reflected in a larger standard deviation. If, for example, the standard deviation of the lead time for replenishing parts increased from 7 days to 10 days while all other numbers stayed the same, there would then be a 99% probability of at least one stock-out and a 50% probability of having 6 or more simultaneous stock-outs.

4.2.3.2 Modeling ABC Inventory Stocking

As discussed in the previous sections, DBV analysis can be used to break a Bill of Materials for a product or family of products into three families: A-parts, B-parts, and C-parts. Carrying out this exercise of analyzing the volume-weighted costs of the purchased parts that are used in the manufacture of offload assemblies (ignoring the effects of 90-dash subassemblies) results in the Pareto chart in Figure 7.

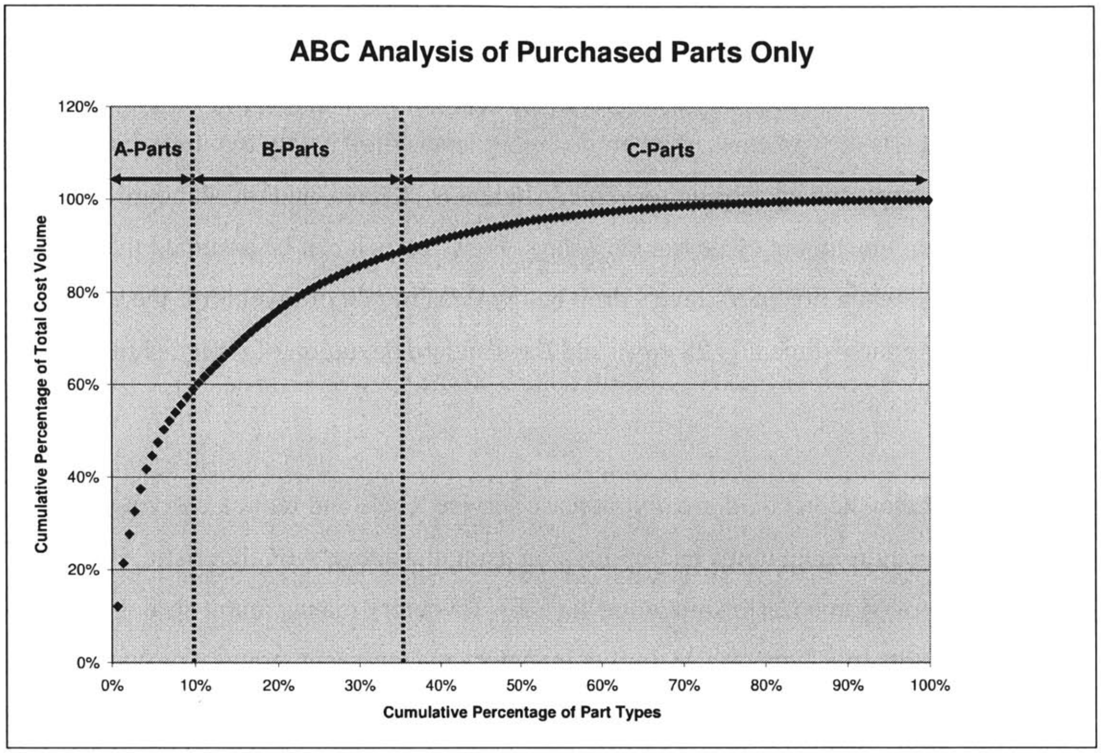

Figure 7: DBV Pareto Chart for Purchased Parts Only

The Monte Carlo analysis applied to Raytheon's estimated historical inventory management strategy can be extended to a hypothetical ABC strategy and the two systems compared and contrasted. The first assumption is that A-parts would be stocked at levels that are lower on a percentage basis but that would provide for a high service level. The associated lower inventory costs would reduce inventory carrying costs. Furthermore, their replenishment cycle times would be highly scrutinized and, therefore, shorter and less variable. Along the same lines, B-parts would be stocked at moderate levels and their replenishment cycle times would be somewhat scrutinized. C-parts would have the highest stocking levels and the least scrutinized replenishment cycle times. It would be expected that the high stocking levels would make it highly unlikely that a delivery would be so late as to result in a stock-out. The financial costs of maintaining high stocking levels of C-parts is offset by the low cost of C-parts.

For A-parts it can be assumed that parts are replenished when inventory levels drop below one month of inventory, the expected cycle time for replenishment is 21 days, and the standard deviation of replenishment cycle time is 3 days. For B-parts, it can be assumed that parts are replenished when inventory levels drop below two months of inventory, the expected cycle time for replenishment is 28 days, and the standard deviation of replenishment cycle time is 7 days. For C-parts it can be assumed that parts are replenished when inventory levels drop below three month of inventory, the expected cycle time for replenishment is 28 days, and the standard deviation of replenishment cycle time is 10 days.

It appears that Raytheon could greatly increase service levels and reduce carrying costs by scrutinizing individual items and optimizing using the above ABC heuristic. Running the same type of Monte Carlo simulation for ABC inventory management strategy and comparing results to Raytheon's historical inventory management strategy provides a striking contrast. The simulation suggests that there is less than a 2% probability that there will be any stock-outs when using ABC inventory management strategy.

4.2.3.3 Approximating Carrying Cost of Inventory using Opportunity Cost of Capital

While there are several costs associated with carrying excess inventory (storage space, handling costs, risk of obsolescence due to a design change, etc.), the primary costs associated with small electronic parts is usually the opportunity cost of capital. The opportunity cost of capital can be thought of as the cost of having money tied up in depreciating inventory instead of being available for investment in the company, financial instruments, etc. The annual cost of capital for inventory can be assumed to be approximately equal to the average value of inventory multiplied by the weighted average cost of capital (WACC) for the specific company. All calculations were performed with an assumed WACC of 10% for Raytheon and an average inventory level of 1.5x the replenishment value.

4.2.3.4 Summary of Simulation Parameters

Inventory Strategy/Type	**Days of Inventory per Replenishment Order (days)**	**Mean Delivery Time for Replenishment (days)**	**Standard Deviation of Delivery Time (days)**
Historical Estimate, Ideal	45	28	7
Historical Estimate, Realistic	45	28	10
A-Parts	30	21	3
B-Parts	60	28	7
C-Parts	90	42	10

4.2.3.5 Summary of Monte Carlo Simulations of Service Level

Inventory Strategy	**Probability of 0 stock-outs**	**Probability of 1 or more stock-outs**	**Probability of 6 or more stock-outs**	**Average Inventory Value**	**Annual Opportunity Cost of Capital**
Historical Estimate, Ideal	33%	66%	<1%	$289,000	$29,000
Historical Estimate, Realistic	<1%	>99%	>50%	$289,000	$29,000
ABC	>98%	<2%	~0%	$294,000	$29,500

4.2.3.6 Discussion of Simulations

The most striking take-away from the above table of results is the massively improved service level achieved with ABC inventory replenishment with a marginal increase in average inventory levels. It does appear that minimizing the inventory levels for the high-value parts that make up the A-parts greatly reduces the average inventory levels and, therefore, the opportunity cost of capital. Clearly, the key to realizing these increases in service level and decreases in inventory costs is to reduce variability in the variability in delivery times for A-parts. The ABC inventory strategy relies on the ability to closely control the deliveries of a few costly parts. It should be mentioned, however, that only 14 of the 143 total part types qualified to be A-parts. Because so few parts must be tracked closely, there is a high probability of success.

It is also valuable to point out that the historical inventory strategy used at Raytheon is highly dependent on the variability of replenishment cycle times. If an ABC inventory strategy is not pursued at Raytheon, this variability in delivery times must be the focus of Raytheon's supply chain management.

4.2.4 Analysis of Current Inventory Levels

The previous Monte Carlo models of inventory replenishment, while illustrative of how best-practices can improve both service level and inventory carrying costs, is not truly representative of reality. In a prior decision, Raytheon project management opted to purchase the majority of the required parts through the end of the contract to mitigate the risk of suppliers changing their designs to suite higher volume customers. At the time of this project, approximately 66% of the value of piece parts required through 2004 and 2005 had already been purchased by Raytheon.

While the stockpiling of such large inventories of parts could potentially guarantee very high service levels, the actual inventories are such that part shortages remain quite common. In fact, the above Monte Carlo simulation of "Historical, Realistic" does indeed appear to give fairly realistic results for service levels. Figure 8 graphically shows the disparity between present and the suggested ABC inventory stocking levels. Assuming that Raytheon could implement an ABC inventory system and that the lead times for A-parts could be made more deterministic, the straight pink line (suggested ABC line) in Figure 8 could be considered to be an "optimal" stocking level. Any blue dot above the straight pink line therefore has excess inventory and any blue dot below the straight pink line has too little inventory.

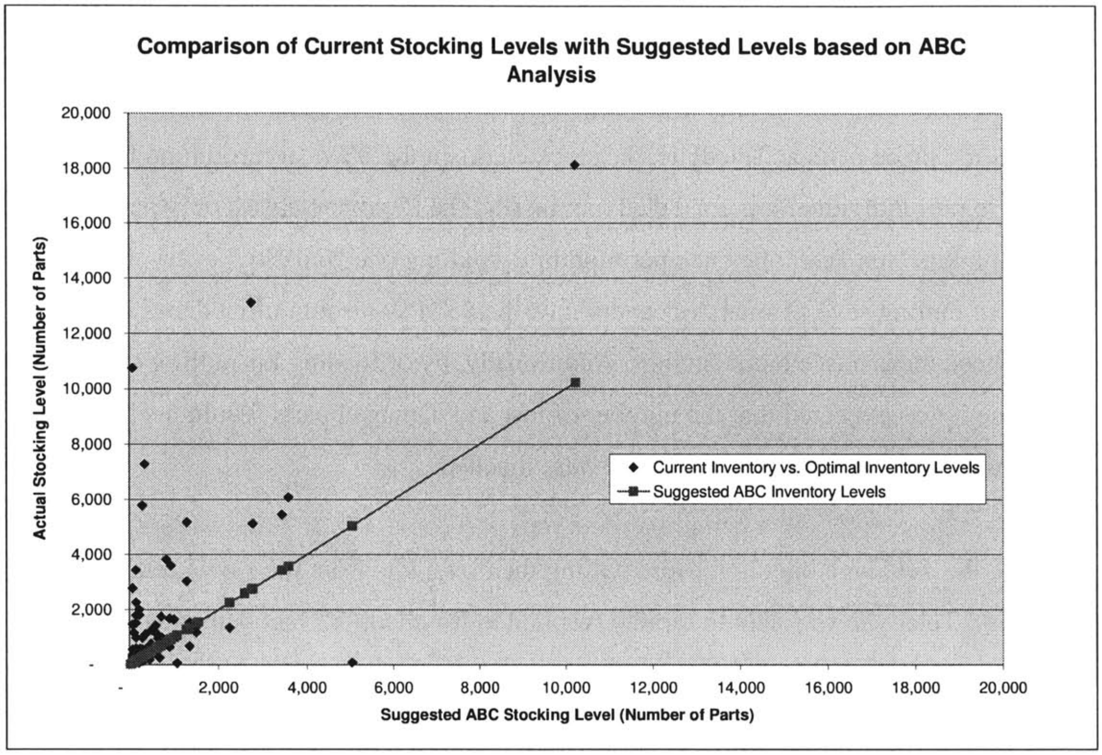

Figure 8: Comparison of Current Inventories with ABC Optimal Levels

There does not appear to be a strong correlation between the actual inventory levels and the ideal ABC levels. Worse yet, several of the parts that have huge excess inventories are also relatively expensive per part. These excess inventories result in large opportunity costs of capital. Based on different assumptions, the annual opportunity cost of capital associated with excess inventory is between $130,000 and $180,000. Given that the total monthly spend on purchased parts is only ~$130,000, these carrying costs are extremely high.

4.3 Bulk Kitting of Piece Parts for Teledyne

4.3.1 Overview

After performing the previous Distribution by Value analysis, it became clear that the easiest way to simplify the product flow for manufacturing offload assemblies would be to allow Teledyne to manage their own inventory of purchased piece parts.

By stocking piece parts at Teledyne, the stock clerks in the SSM storeroom no longer needed to pull individual kits for Teledyne. Instead the Raytheon clerks only needed to pull "bulk kits" for Teledyne once per month. By pulling one "bulk kit" every month instead of pulling several small kits every day, the SSM storeroom immediately experienced measurable labor savings. Additionally, by offloading kit-pulling to Teledyne it was expected that the number of lost and damaged parts would decline due to a reduction in the number of times parts were touched.

Because the Teledyne operators were pulling their own kits from their own remote inventory, Teledyne was able to rapidly respond to Raytheon's exact demands. This ability to respond quickly would enable a dramatic decrease in the cycle time for offload assemblies and an improved service level.

4.3.2 Initial Steps towards Establishing Consensus and Commitment

In order to secure commitment from all the key stakeholders, a number of "blitzes" were held to discuss how best to carry out bulk kitting. Blitzes were simply large meetings attended by all of the key managers and stakeholders needed to make decisions. Because bulk kitting would affect a number of people in both Raytheon and Teledyne, it was necessary to bring together managers from both companies. Representatives from Production and Inventory Control (Raytheon), Supply Chain Management (Raytheon), Engineering (Raytheon), Operations (Teledyne), and Quality Assurance (Teledyne and Raytheon) were all involved in the initial planning process.

To gain commitment from the project stakeholders, the team outlined a clear description of the problem and the project objectives. These goals and objectives were recorded in a flow chart and associated run rules.

The key goals of the project agreed upon by the project team were to:

- Provide Teledyne with all the parts they need to meet Raytheon's release schedule
- Create a spreadsheet tool to create a bulk kit pick-list
- Agree on method to ensure the delivery of the right quantity of the right parts to Teledyne
- Create a simple system to allow Teledyne operators to pull their own kits quickly and without errors

4.3.3 Development of Enabling Technologies and Processes

4.3.3.1 Nicknames for Raytheon-supplied Piece Parts

The piece parts supplied by Raytheon to Teledyne were to be sorted by "nickname" and not by part number. The nickname system allowed an operator at Teledyne to search for a part by a simpler, more familiar nickname instead of its traditional part number. For example, an operator would not search for parts with names such as "SSM1373-003-J-02" or "SSM1373-005-K-02." These two parts would instead have nicknames such as "Bob" or "Sarah." [a]

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[a] The list of potential nicknames was created using Top 1000 Names for 2003 found on the Social Security Administration web site (www.ssa.gov/OACT/babynames/). This list provided 2000 names (1000 male, 1000 female) to choose among. This master list of names was then manually truncated to minimize potential confusion due to creative spelling. For example, "Jenni" and "Jennee" were removed so as not to be confused with "Jenny." These nicknames were then randomized using an Excel spreadsheet. The names on this randomized list were then assigned to the various piece parts that were to be stored at Teledyne. When these parts were stocked at Teledyne, the storage bins were arranged in alphabetical order to effectively randomize the physical locations of the various parts.

Taking advantage of Teledyne's lack of a rigid material resource planning (MRP) system, it was possible to stock parts according to randomly assigned nicknames. By stocking piece parts alphabetically instead of by part number, parts could be stocked randomly (similar parts with similar part numbers would not be located next to one another) and Teledyne operators would be less likely to make "dyslexic" mistakes (resulting in wrong quantities and/or wrong parts).

This nicknaming technique, in the language of Lean, is could be considered an application of Poka-yoke. Poka-yoke can simply be thought of as "Murphy-proofing" a process (referring to Murphy's Law – anything that can go wrong will go wrong).[7] The previous system of simply arranging parts numerically by their part numbers set the stock clerks up to fail. By simply changing the names and making them fun, both efficiency and accuracy were increased.

4.3.3.2 Creation of a Stocking Location at Teledyne

With the help of Teledyne management, a nitrogen-purged "dry" box at Teledyne was reserved exclusively for Raytheon piece parts (Figure 9). The dry box was filled with small totes to hold the piece parts. Each part tote was labeled for a unique part number and nickname. The part totes were then arranged alphabetically by nickname.

Additionally, we set up a dry box specifically to house a remote inventory of 90-dash subassemblies at Teledyne (Figure 10). This stocking location is meant to complement the inventory of piece parts and facilitate the kitting process at Teledyne.

Figure 9: Picture of Remote Piece Part Inventory at Teledyne

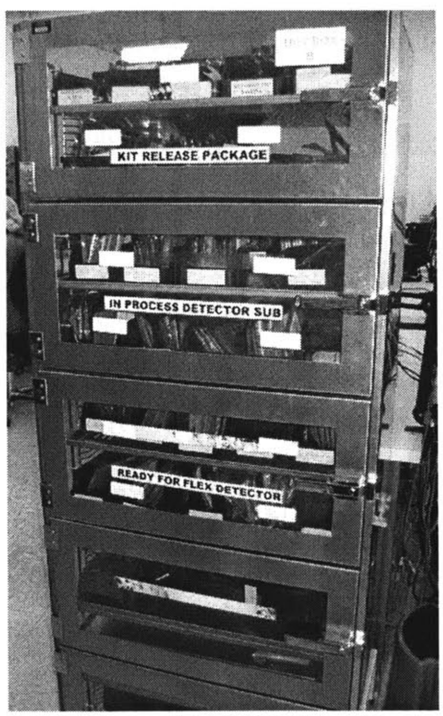

Figure 10: Picture of Remote 90-dash Subassembly Inventory at Teledyne

4.3.3.3 Creation of Bulk Kit Spreadsheet Tool (Bulk Kit Calculator)

The first versions of the Bulk Kit Calculator were created by manually collecting bill of material data from Raytheon's MRP system. This information was entered into an Excel spreadsheet that, using a macro, outputted a pick-list that consolidated the demands for parts common to several assemblies. The resulting pick-list contained a single quantity of each type of piece part, allowing Raytheon stock clerks to pull each part number only once for each bulk kit.

The Bulk Kit Calculator was then given to Teledyne to allow their operators to pull their own kits. The nicknames for each part number were included in the Bulk Kit Calculator, allowing Teledyne to rapidly and accurately pull kits.

4.3.3.4 Agreement on Bulk Kit Inspection Process

In order to be confident that the bulk kits were accurate and to avoid time consuming replacements and corrections, Teledyne agreed to provide an experienced operator to inspect bulk kits prior to the parts leaving Raytheon. This inspector agreed to verify the topologies and quantities of parts and inspect for damage.

4.3.4 Results of Bulk Kitting

4.3.4.1 Process Improvements

The creation of a small, remote stocking location at Teledyne combined with simple software to generate a pick-list and a much more error-proofed part location scheme resulted in a version of a mini-market. Such mini-markets are critical elements of a functional just-in-time (JIT) manufacturing process.[7] The results of bulk kitting echoed the previous findings on using mini-markets in manufacturing – **mini-markets save time.**

A comparison of simple value stream maps before and after bulk kitting was implemented clearly show key results. First, the number of process steps has been reduced significantly. The new process for sending parts to Teledyne has been vastly simplified by sending piece parts in one monthly bulk kit in lieu of several small kits per day.

Shipments of 90-dash subassemblies to Teledyne continue on a more regular basis. 90-dash subassemblies, manufactured at Raytheon, are subject to more extensive handling and tracking. This enhanced tracking reflects the greater value of these assemblies relative to purchased piece parts.

Key Results:

- Teledyne assumed responsibility for managing inventory and pulling kits for offload assemblies while simultaneously decreasing their cycle time, i.e. Teledyne absorbed work that previously caused 3 days of cycle time with no impact on their own cycle time!
- Cycle time for supplying Teledyne with 90-dash subassemblies reduced significantly
    - **Prior to bulk kitting** the cycle time to manufacture and deliver 90-dash subassemblies to Teledyne ranged from 3 days to several weeks, with an **average cycle time of approximately 7 days**
    - **After instituting bulk kitting** the cycle time to manufacture and deliver 90-dash subassemblies to Teledyne ranged from approximately 2 days to 5 days, with an **average cycle time of approximately 4 days**
- Because the inventory of 90-dash assemblies was moved to Teledyne, there is no longer a need to stock 90-dash assemblies in Raytheon's store room
- Raytheon's storeroom benefits from significant economies of scale when assembling bulk kits
    - Drastically reduced number of trips to the same stocking locations
    - Inspection of parts by Teledyne staff can be completed in less than one day per month

- Because bulk kits require relatively large quantities of each part type, many of these parts can be shipped to Teledyne in un-opened "wafflepacks," greatly reducing part handling
- Reduced part handling results in fewer losses and reduced damage
- Co-location of all necessary parts for offload assemblies at Teledyne allows for easier assessment of critical part shortages
- Maintaining all necessary parts at Teledyne and effectively removing Raytheon from the critical path enable:
    - Rapid response from Teledyne
    - Raytheon to dynamically change the lot sizes for offload assemblies, allowing for the maximization of usable inventory for offload assemblies

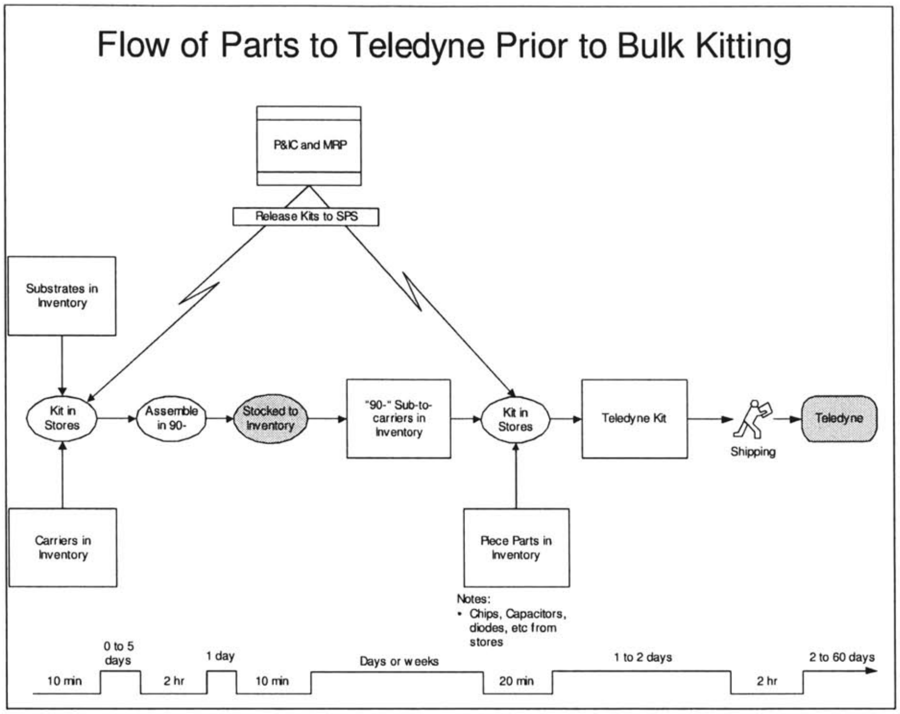

Figure 11: Value Stream Map for Initial Flow of Parts to Teledyne

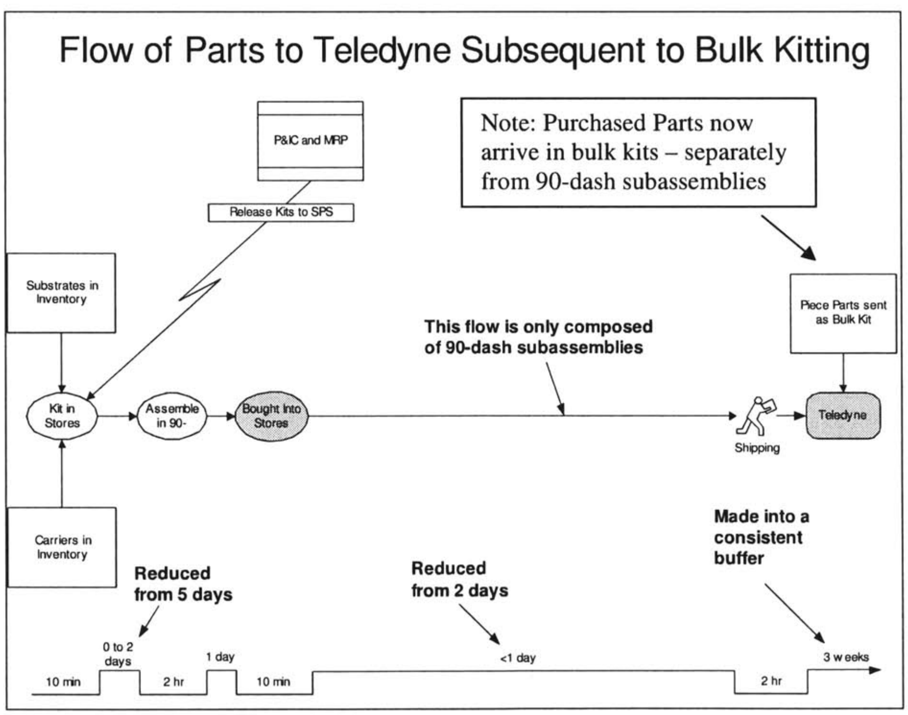

Figure 12: Value Stream Map for Flow of Parts to Teledyne after Implementation of Bulk Kitting

4.3.4.2 Summary of Impacts of Project

Improvement	Benefit or Labor Savings
Pull one bulk kit per month instead of 100+ individual kits	Saves ~17 hours of labor per week
Eliminates time to stock 90-dash parts into SSM inventory	All 90-dash parts go directly to Teledyne, where Teledyne maintains a remote inventory (1.2 hours per week)
Frees up 90-dash stocking space in Raytheon storeroom	New stocking location at Teledyne frees up some space in Raytheon storeroom dry boxes

Figure 13: Analysis of Accomplishments and Benefits

Explanation of Benefits

Pull one bulk kit per month:

17 hours/week savings is based on stock clerks only retrieving parts from a stocking location once per month, efficiencies in processing kit paperwork, and efficiencies in inspecting and mitigating issues.

Eliminates time to stock 90-dash subassemblies into Raytheon inventory:

All 90-dash subassemblies produced at Raytheon will be shipped directly to Teledyne. This new process eliminates the 5 minute stocking process previously required for each 90- kit.

4.3.5 Bulk Kitting Conclusions

As evidenced by the decrease in total manufacturing cycle times for offload assemblies, it was more efficient for Teledyne operators to kit their own parts from their own remote inventories. These remote inventories, augmented with simplifying technologies and divorced from Raytheon's stifling MRP system, became functional mini-markets. These mini-markets enabled Teledyne to respond to Raytheon's delivery demands with Just-in-Time (JIT) deliveries of finished offload assemblies. Given this success, it seems reasonable that Raytheon should consider setting up similar mini-markets at other contract manufacturers' facilities. Further, Raytheon should consider setting up similar, semi-autonomous mini-markets within its own internal manufacturing facilities.

5 Implementing a Pull System using "Pods"

5.1 Requirements for an Offload Assembly Production System

The primary reason for implementing a lean, pull-based production system for the manufacture of offload assemblies was to explicitly link manufacturing to consumption of offload assemblies. It was critical that the new production system automatically trigger manufacturing priorities for both Raytheon and Teledyne operators. Further, a lean system with minimal work in process (WIP) was required in order to both reduce the amount of capital tied up in WIP and minimize the clutter in work stations. With less clutter the operators could more easily keep track of priorities and assess their progress towards production goals.

Analysis of Raytheon's and Teledyne's manufacturing capacities further highlighted the need for a production system to automatically maximize the ratio of usable to unusable inventory of offload assemblies. This system was also required to be fairly robust and easy to understand and follow. Because the manufacture of offload assemblies is well understood and the demands are quite predictable, it was expected that a system could be developed that did not require formal project management.

Finally, it was required that any new production system be extremely visual. It was desired that the new system be intuitive, with all containers clearly labeled and all processes explicitly mapped in posted process flow charts.

5.2 Description of "Pods"

A "Pod" was created as the main tool in organizing offload assemblies in the new offload assembly production system. A "Pod" is simply a black, plastic tote box that has been customized with dividers to create sub-compartments and colorful labels (Figure 14).

The ultimate goal of the Pod system was to regulate the flow of offload assemblies to Raytheon, ensuring that Teledyne had proper priorities and guaranteeing that Teledyne only ship parts that Raytheon requested. In requiring that Teledyne only ship parts that Raytheon can use, it was hoped that the Pod system would reduce the inventory of unneeded (and expensive) finished offload assemblies at Raytheon. By reducing inventory levels and enhancing the communication of work priorities (allowing load leveling at Teledyne), the Pod system was intended to enable just-in-time deliveries from Teledyne to Raytheon.[8]

Each Pod was intended to represent one type of MIC. Each MIC's Pod was designed to carry the quantity and variety of offload assemblies required to manufacture two weeks worth of that MIC. An example of the calculations used to determine Pod sizing is given in Figure 15.

The Pod system was designed to support all ten MICs which incorporate offload assemblies manufactured by Teledyne. Because each of these MICs were unique and required different offload assemblies, each of these MICs required a unique Pod or pair of Pods with appropriate labeling. In total, three sets of 13 Pods were deployed to support these ten MICs. In general, one set of Pods was expected to be at Raytheon, and two sets of Pods were expected to be at Teledyne. Of the two sets of Pods at Teledyne, the first set was to be in an active work queue and the second set was to function as a buffer.

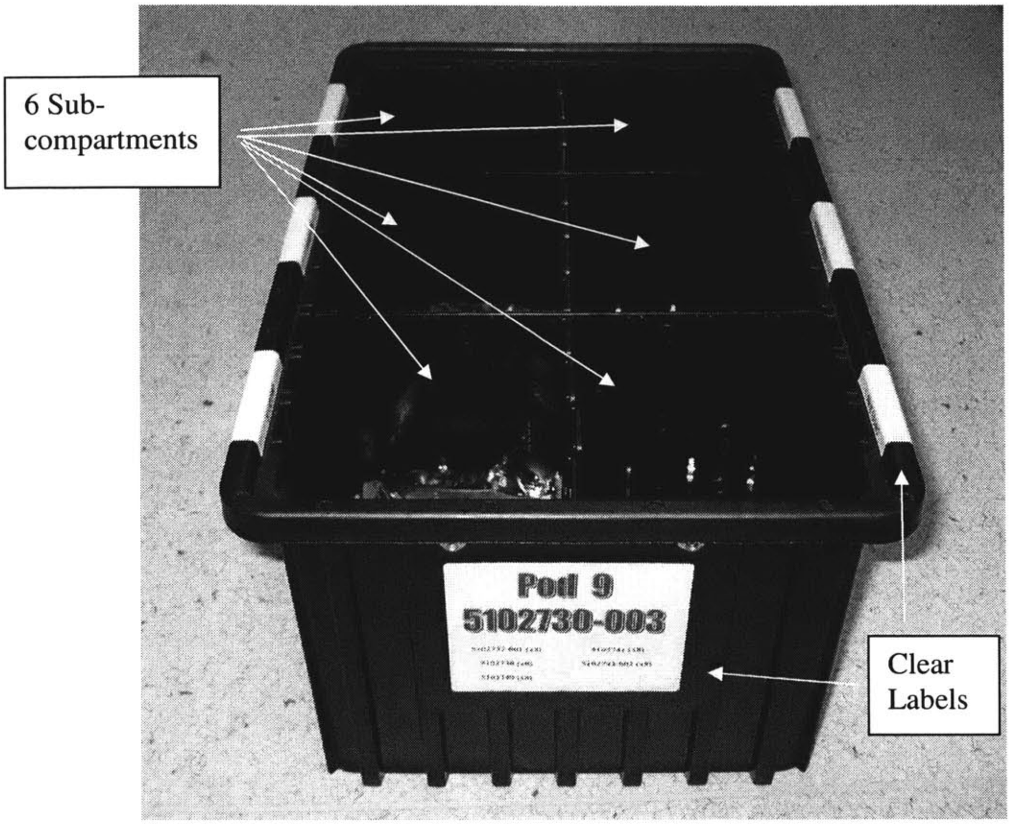

Figure 14: Picture of a Pod

Pod #5 Corresponding Microwave Integrated Circuit - MIC#5			
Offload Assemblies Used in MIC#5	Number of Each OA Required to build one MIC#5	Two-week Demand for MIC #5	Required OA's in a Full Pod
OA #1	1	8	**8**
OA #2	1	8	**8**
OA #3	1	8	**8**
OA #4	1	8	**8**
OA #5	1	8	**8**

Figure 15: Example Calculation of Pod Capacity Requirements

Outside Dimensions of Pods

Because Pods were envisioned as the primary method for organizing and transporting offload assemblies within Raytheon's factory and between Teledyne and Raytheon, correct sizing was critical. Offload assemblies normally are stored in Nitrogen-purged dry boxes, so it was necessary for Pods to fit in the existing dry boxes used at Raytheon and Teledyne (Figure 16). Several different types of dry boxes were used in Raytheon's different manufacturing areas, so the smallest dimensions were used as constraints.

Figure 16: Picture of a Pod inside a Nitrogen-purged Dry Box

Electrostatic Characteristics

Offload assemblies are, themselves, delicate microwave integrated circuits. Because these assemblies are sensitive to static discharges, it was deemed necessary for the Pods to insulate offload assemblies from electromagnetic interference (EMI), electrostatic or induced fields. Black totes made of Bentron™ black static-protective material were used to ensure acceptable electrostatic characteristics.

5.3 Pod Process Details

It should be noted that the Pod Process is an ongoing, circular process with no true beginning or end. Determining "Step 1" was arbitrary but is consistent with the Pod Process Flow Chart shown below. See Appendix B for a graphical process flow chart.

Step 1: Receipt of full Pod in Raytheon SSM storeroom

It may be useful to consider the initial receipt of a Pod from Teledyne as a logical beginning of the Pod replenishment cycle. The Pod is expected to full, i.e. all of the offload assemblies required to produce the MIC associated with the Pod are present. Additionally, it is required that the Pod contain a specific quantity of each of the required offload assemblies. By requiring specific quantities of the offload assemblies, it is possible to maintain nearly 100% usable inventory.

The Pod arrives at Raytheon's receiving dock and the receiving personnel process paperwork to acknowledge receipt of the offload assemblies. The Pod is then transported to the SSM storeroom where it is placed in its specified dry box storage location. These storage locations are labeled and have clear plastic doors. As shown in Figure 17 and Figure 18, these storage locations are highly visible and the inventory for each of the MICs/Pods can be quickly assessed by simply glancing at the location in question.

Figure 17: Picture of Pods in their Respective Storage Locations

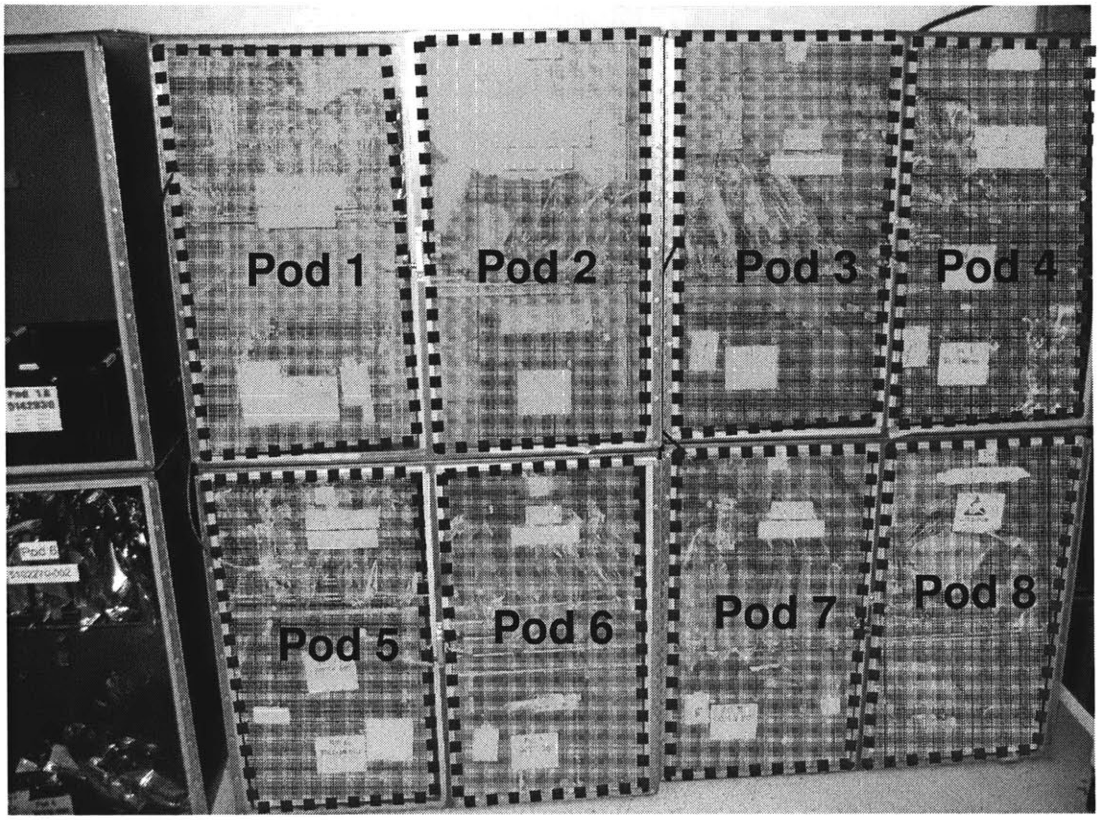

Figure 18: Pod Storage Locations with Labels for Clarity

Step 2: Consumption of offload assemblies

The final assembly of MICs begins with a "top kit." Each top kit contains all of the subassemblies, piece parts, and housing components required to make one complete MIC. The SSM storeroom maintains approximately one week's worth of top kits for each of the 10 MICs affected by the Pod system. The storeroom supervisor directs stock clerks to pull top kits whenever the buffers are running low. When pulling top kits, the stock clerks obtain all necessary offload assemblies from the available Pods and obtain other parts from various locations within the storeroom.

When the first set of offload assemblies is removed from a full Pod, then that Pod is referred to as having its **"seal broken."** Once a Pod's seal is broken, the storeroom supervisor sends an email to notify Teledyne. This email from Raytheon functions as an electronic Kanban or E-ban. When Teledyne receives this E-ban, they effectively are authorized to build and ship one replacement Pod.[9]

It is agreed that Teledyne will ship a full replacement Pod to Raytheon within two weeks of receipt of this E-ban. This two week window corresponds to the expected time until the Pod at Raytheon is emptied. This two week time frame is directly determined by the size of the Pods.

Step 3: Teledyne places an empty Pod at the end of its FIFO Pod queue

Teledyne, upon receiving the E-ban signal from the Raytheon storeroom, then retrieves an empty Pod of the same variety. As discussed in Section 5.2, Teledyne maintains both a set of Pods in an active queue and a buffer set of Pods. The E-ban functions as the signal to move an empty duplicate of the Pod that had its seal broken from the buffer to the active work queue. For example, if Teledyne received an E-ban from Raytheon after the seal was broken on Pod #7, then Teledyne would retrieve an empty duplicate of Pod #7 from its buffer and place it at the end of the active work queue.

The new Pod that is being added to the work queue should be placed at the end of the queue. Because the flow of Pods is First-In-First-Out (FIFO), this newly added Pod is the lowest priority. This new Pod is expected to move up the queue and be completed and delivered to Raytheon within two weeks of the E-ban signal.

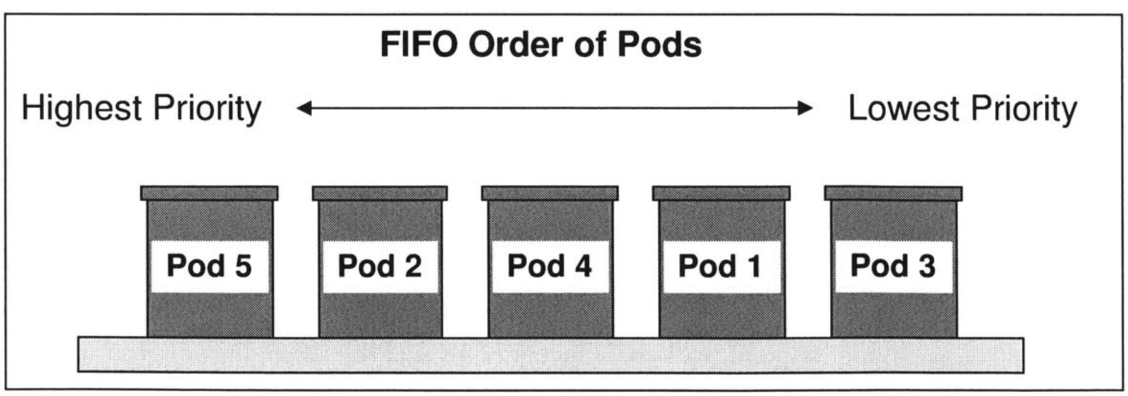

Figure 19: Illustration of FIFO Pod Queue at Teledyne

Step 4: Teledyne "attacks" Pods according to FIFO queue

The physical order of the Pods in Teledyne's workspace functions as the priorities for the Pods. Teledyne is expected to concentrate all of their efforts on completing the Pods at the front of the FIFO line. In concentrating on, or "attacking" the top-priority Pods, Teledyne is responsible for informing Raytheon of any part shortages that could delay shipments.

Teledyne agreed to ship only full Pods, thus ensuring an extremely high ratio of usable to un-usable inventory of offload assemblies.

The ideal FIFO flow of Pods is illustrated in the following figures:

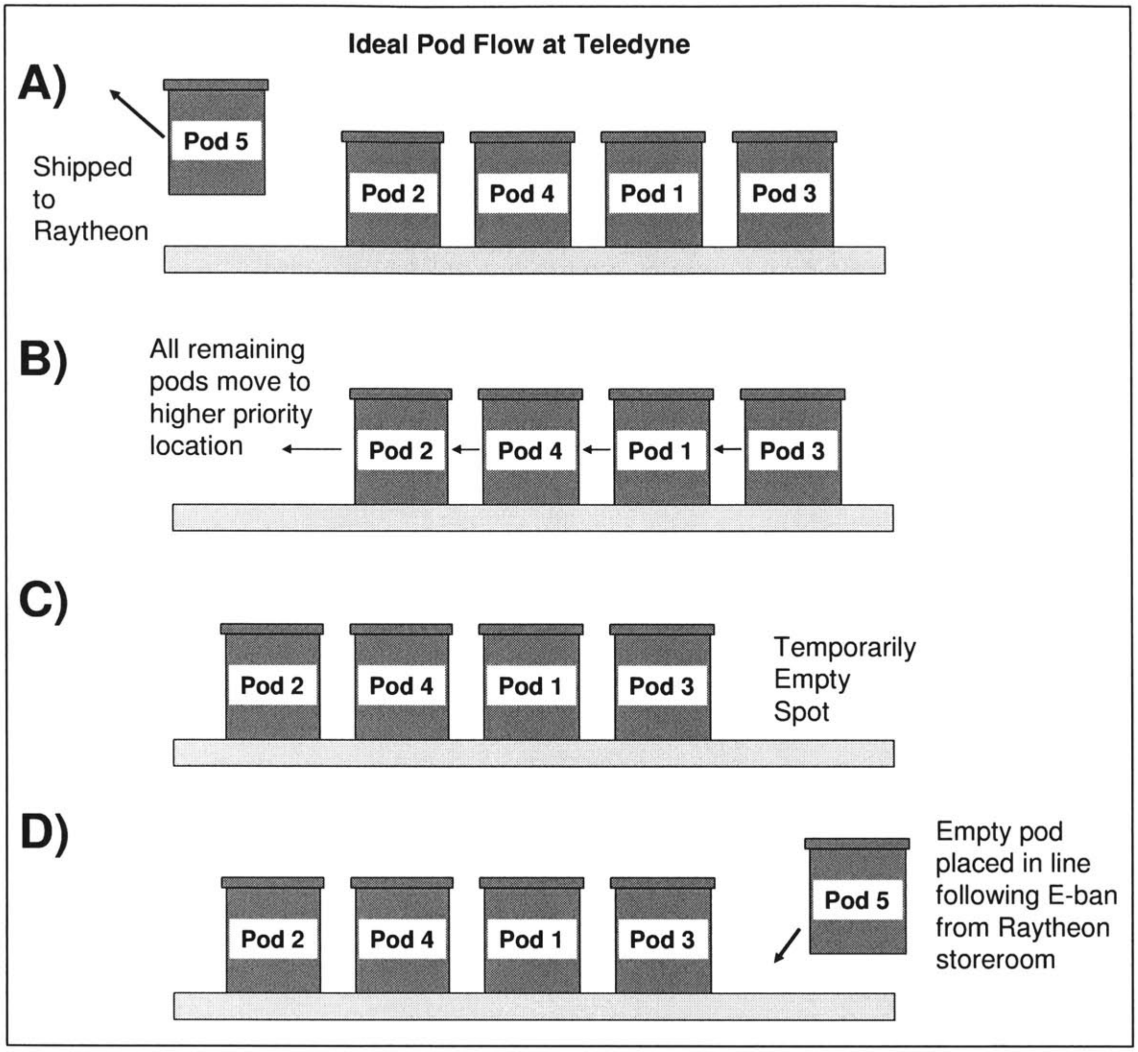

Figure 20: Ideal FIFO Pod Flow at Teledyne

5.4 Ramp-up Issues

Implementation of a new, lean pull system was fairly complicated for variety of reasons. Although the first Pods were not released into production until November of 2004, nearly five months after the disastrous fire in the SSM, several areas within Raytheon were still operating in recovery mode. Due to the need to rely solely on outside vendors for substrate materials, the availability of critical raw materials was still quite unpredictable. Additionally, the new Pod system required different behaviors both at Raytheon and Teledyne.

5.4.1 Establish Reliable Inventory Levels

As mentioned in Section 2.3.5, the MRP system used by Raytheon was not easy to use and master print out of inventory levels, or "tab runs," were normally woefully out of date and of limited use. Consequently, simply establishing an accurate inventory count was extremely difficult to do. Initial audits of physical inventory at both Raytheon and Teledyne established beginning inventory levels.

5.4.2 Creation of quantity requirements for each specific offload assembly

One of the most critical early challenges was to use the dynamic information relating to inventory levels to create a "grocery list" of the offload assemblies Raytheon needed and the exact quantities of each offload assembly needed. The ultimate goal of this first wave of Pods was to bring all inventory levels of offload assemblies to a point where the percentage of usable inventory was 100%. Once these inventories were "evened up," it would then be possible to ship full Pods with the knowledge that all of the offload assemblies in that Pod would be "usable" and could be built into a MIC immediately.

5.4.3 Monitoring Teledyne priorities and production

Once Teledyne had been supplied with a comprehensive list of offload assembly priorities and quantities, it was necessary to validate that Teledyne only ship parts called out on the above-mentioned "grocery list" or priority list.

One step that was critical to holding Teledyne accountable for their shipments was a modification to the contract between Teledyne and Raytheon. Teledyne agreed to only ship parts to Raytheon that had been explicitly requested. These shipments could either be in full Pods, nearly-full Pods authorized by Raytheon, or individual replacement parts requested by Raytheon.

5.5 Results and Risks

As with any new system, the Pod system began with some successes and some failures. Despite initial confusions about which parts were allowed to be shipped, Teledyne eventually became comfortable with the concept of "attacking" one Pod at a time. Following this strategy simplified the process of determining manufacturing priorities.

One key risk associated with the Pod system is the requirement that Teledyne hold a certain level of finished inventory that is not shippable. Because Teledyne cannot ship partial Pods without Raytheon's approval, Teledyne can find itself "stuck" with un-shippable offload assemblies due to manufacturing problems at Teledyne or part shortages at Raytheon.

6 Examination of Organizational Structures for Stakeholders

6.1 Introduction

The three organizations most affected by the project are Solid State Microwave (SSM), Supply Chain Management, and Teledyne Inc. In this section the organizational structures of each party are presented. Based on these structures, recommendations are given for supporting the new lean systems.

While previous chapters were primarily based on collected data and discussions of actions, the following two chapters are based on interactions, interviews, and personal opinions. These chapters are not necessarily reflective of all or most units or employees within Raytheon or Teledyne.

6.2 Raytheon Solid State Microwave - Structure

Solid State Microwave (SSM) is a unionized, operational division of Raytheon SAS responsible for manufacturing MICs and circulators (a critical component used in the antenna arrays for various radar systems). The production goals for SSM are somewhat complicated due to the facility's dual purpose. SSM is primarily a manufacturing facility tasked with delivering products to downstream customers (internal to Raytheon but in different geographic locations). Concurrently the design engineers take advantage of SSM's specialized manufacturing and test equipment in order to rapidly build and test prototype microwave circuits.

In order to maintain proper focus on the throughput of purchased units, a number of project managers are responsible for tracking a group of products through the shared resources of SSM operations. These project managers report to the director of SSM operations while also reporting to the VP of operations in Raytheon SAS. The director of operations in SSM ultimately oversees the allocation of shared resources (both people and equipment) in SSM to the various project managers and design engineers.

The projects supported by the project managers are subcomponents of substantial, long-term contracts with governmental customers. These projects are often fixed-price and have very predictable delivery schedules explicitly stated in the contracts. Efficient operations are naturally critical to maximizing profits on these fixed-price contracts.

6.3 Raytheon Solid State Microwave - Metrics and Incentives

The key metrics in SSM in the eyes of management are the output of Microwave Integrated Circuits (MICs), output of circulators, and the department's ability to keep up with the desired production "drum beat" or takt. Operators on the SSM factory floor are measured in terms of individual output and quality of parts produced.

In a unionized environment, creating meaningful incentives for operators can be complicated. The most basic distinctions among operators are seniority, certifications, and labor grade. The seniority of an operator is simply the number of years the operator has been working at Raytheon (or General Motors before that or Hughes Aircraft Company before that). An operator's seniority largely determines the order in which employees are laid off in the event of downsizing – those with the least seniority are the first to be laid off.

Certifications allow an operator to both perform and inspect various operations on the shop floor. An operation-specific certification is granted to operators who have consistently performed quality work and have completed formal training in that specific operation. In addition to giving the operator the autonomy to perform and inspect his or her own work, these certifications are also needed in order to move to a higher labor grade.

Labor grade refers to the general skill level of an employee and a corresponding spectrum of possible pay rates. There are very few distinct labor grades, with nearly all of the SSM operators in one of three or four labor grades. Most of the operators have many years of experience and are often at the top of their labor grade. When one is at the top of his or her labor grade, the union contract does not permit further pay raises without an increase in labor grade.

Raytheon managers can use merit raises to reward outstanding performance as well as a number of recognition-based rewards. Among these recognition-based rewards are "On the Spot" awards, plaques, and commendations during meetings.

6.4 Raytheon Supply Chain Management - Structure

Supply Chain Management is a unionized, functional division of Raytheon SAS which supports the company's various engineering, product and operational divisions. Supply Chain customers within Raytheon are charged a "Handling Rate" allocation based on a percentage of material dollars received on a monthly basis. All costs and cost savings are allocated to all Raytheon customers. This general allocation of costs is commonly referred to as the "peanut butter effect" because the costs associated with Supply Chain are allocated across the various business units evenly, regardless of direct Supply Chain costs. As a result, customers who demand higher service but have relatively small materials needs (in dollar terms, such as SSM) benefit disproportionately from this costing structure. This handling rate is considered a site strategy, allowing some activities to be "subsidized" and remain competitive.

Warehousing, a subunit of Supply Chain Management, is charged with running the storeroom that maintains most of the inventory for SSM operations. This storeroom directly supports the SSM production floor by preparing kits of parts as well as by maintaining stocks of needed purchased parts. Production and Inventory Control (P&IC), another subunit of Supply Chain, is charged with interpreting the various product schedules, as shown in the MRP system, and controlling the release of kits to the SSM production floor for assembly. P&IC, with the input from project managers and SSM operations management, is in charge of making sure that the right mix of parts is on the floor at any one time.

6.5 Raytheon Supply Chain - Metrics and Incentives

Supply Chain metrics are focused on the quality of service that supply chain provides to its internal customers. Warehousing managers, due to their integrality with the production floor, are fundamentally valued according to their ability to supply operators with parts. In other words, it is the storeroom's job to never force the operations floor to wait for a part.

P&IC managers and Supply Chain employees who directly purchase parts from outside vendors are primarily focused on minimizing per-part prices. As a result it is common for parts to be purchased in the largest quantities possible given Raytheon's projected demand for a part. Accordingly, there is little focus on the carrying cost of inventories held at Raytheon. In fact, the majority of purchased parts needed for the life of the project in question had already been purchased and were in stock. While the decision to purchase all parts several years in advance may have been a sound decision from an engineering standpoint, there did not appear to be any quantitative treatment of the carrying costs associated with this large purchase.

> *"A purchasing department that functions as a separate unit, restricted to cutting purchase orders, expediting parts, and trying to wring price concessions from suppliers, does not produce the best results. Instead, [Purchasing and Supply Management] must be a horizontal, integrated process encompassing most areas of spending and all important users, led and supported by top management."* [10]

Stock clerks in Raytheon Supply Chain are measured mainly on the accuracy of the kits that they prepare. Kits with incorrect parts, incorrect quantities, or damaged parts are returned to the storeroom for corrective action. These mistakes are closely tracked.

Supply Chain stock clerks and SSM operators are represented by the same labor union. As a result, the incentives for Supply Chain stock clerks are essentially identical to those for SSM operators.

6.6 Teledyne – Structure and Incentives

Teledyne Microelectronic Technologies is a non-union contract manufacturer located approximately 15 minutes from Raytheon. Since 2000-2001, Teledyne has performed several manufacturing steps that were previously done in-house by Raytheon SSM. These manufacturing steps were offloaded to Teledyne in order to substantially increase throughput capacity during a sizable increase in production volume at Raytheon.

Prior to the Raytheon fire in July, 2004, the relationship between Teledyne and Raytheon was fairly distant and hands-off. Teledyne was supplied with kits of parts to build and a rough, often changing list of daily work priorities. Generally, Raytheon provided Teledyne with minimal forecast demand data or feedback. Teledyne was paid for shipments of completed assemblies when the parts arrived at Raytheon's receiving dock.

Since the initiation of this relationship between Raytheon SSM and Teledyne, Teledyne has maintained a small lab area approximately 80% dedicated to manufacturing Raytheon products with a staff of approximately 5 or 6 operators and a line manager. As Raytheon demands have changed, Teledyne has increased or decreased staffing accordingly.

Teledyne, like Raytheon SSM, is an organization focused on profits from efficient operations and maximizing product throughput. Project managers are focused on the profitability and on-time deliveries of a portfolio of products and act as the main point of contact with customers outside of Teledyne. In parallel an operations manager is focused on equitably allocating the company's shared resources.

As of the time of this project, Teledyne receives payment for completed offload assemblies when these offload assemblies are officially received at Raytheon's shipping and receiving dock. Upon rudimentary inspection at Raytheon's receiving dock, a payment is automatically issued to Teledyne for the offload assemblies. Each type of offload assembly requires differing amounts of labor and, as a result, Teledyne receives compensation proportionate to the labor content for each offload assembly. It is also important to note that Teledyne receives no financial bonuses or penalties for on-time/late deliveries or good/bad quality.

6.7 Structural Recommendations

In order to align incentives, three key things must happen:

(A) Warehousing costs and cost savings need to be accurately allocated to SSM operations.

- Without a clear link between lean efforts and cost savings for all involved, it is difficult to sustain operational gains due to lean initiatives.
- If warehousing continues to be allocated to internal customers like "spreading peanut butter," operations will only focus on improving supply chain service level and there will never be fully aligned support for cost savings in supply chain.

(B) When Raytheon discusses piece prices and labor costs with Teledyne, SSM Operations managers and project managers must be involved and must understand the dollar benefit of steady part flow from Teledyne

- When price negotiations are undertaken without representation by direct customers, there is a high likelihood that the importance of the per-part price will be overemphasized and expected service level will be underemphasized.
- It is important to quantify the value of adequate and inadequate service level from contract manufacturers.

(C) Teledyne must be made a financial, as well as manufacturing, partner through an enhanced incentive structure

- Contracts for outsourced manufacturing in the critical path should include incentives for on-time deliveries and penalties for late deliveries.

- Proper incentives create risk sharing, which focuses both Teledyne and Raytheon on cost savings and product flow.

(D) Re-align supply chain metrics to focus on reducing total cost of ownership for inventory

- Instead of focusing on per-piece price of parts, make purchasing decisions based on per-piece prices of parts, marginal warehousing costs for holding excess inventory, the cost of capital tied up in excess inventory, and the transaction costs associated with issuing purchase orders and negotiating prices.
- Such metrics will likely encourage the adoption of Supplier Managed Inventory (SMI), a Raytheon initiative where "inventory data is sent to suppliers who assume the responsibility for managing their inventories inside [Raytheon's] organization." [11, 12]
- As stated in recommendation (A), the operational units in Raytheon (Supply Chain's customers) need to directly benefit from cost savings resulting from SMI and other Supply Chain initiatives resulting in cost savings.
- New Supply Chain initiatives, such as SMI, will initially result in costs (new process development, training, etc.), therefore a cost-allocation system must exist to encourage operational units to shoulder these initial costs so that Raytheon can eventually reap the cost saving benefits of systems like SMI.

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7 Examination of Project – Cultural Lens

7.1 Introduction

In this section the cultural landscapes of the key stakeholders are explored. Based on these cultural observations, conclusions are drawn about the sustainability of lean initiatives like the project discussed in this thesis.

7.2 Solid State Microwave History

Solid State Microwave (SSM) has been an important division of Raytheon SAS for nearly 20 years consistently building MICs that incorporate world-class technology. Around the year 2000 SSM was faced with huge manufacturing and operational challenges. New contracts for radar systems were forcing SSM to approximately double its throughput of MICs. While new contracts are normally viewed positively, this need for expanded capacity came at a time when Raytheon was cutting costs and consolidating locations to minimize real estate costs. SSM, being located in Southern California, was especially costly. As a result, SSM was asked to double throughput while also halving the footprint of the factory floor. To this end, Raytheon brought in a "Red Team" of highly experienced and motivated managers to guide this transition. The "Red Team" introduced SSM operations to several key lean concepts and instituted a CONWIP-based pull system for MIC production. Production was measured relative to a desired takt, a metric that is now the key performance measure in SSM. Several successful lean concepts were implemented, yielding a more efficient and predictable product flow and drastically reduced work-in-process inventories. Reorganization of work stations according to logical work flows also allowed SSM to produce nearly twice the throughput in a factory with about half the physical footprint SSM is now regarded throughout the various operations divisions in Raytheon as the leader in lean thinking.

7.3 Raytheon Supply Chain History

The Supply Chain division of Raytheon was, until fairly recently, simply known as purchasing. For many years the primary responsibilities for the buyers and planners in purchasing were to minimize per-part prices through bulk purchasing and to manage the technical and legal difficulties of purchasing parts for use in government and military applications. For years this purchasing division was viewed by operations and engineering simply as being "in the way." All of the technical understanding of how parts were to be used was in the hands of engineering and operations while purchasing could only provide minimal guidance in regards to strategic sourcing, inventory theory, total cost of ownership, etc.

As Supply Chain has matured and attempted to build up capabilities in modern supply chain concepts, the division has continued to be hamstrung by the negative perception of purchasing and Supply Chain. Worse yet, Supply Chain retains a strong culture from its days as purchasing. Many within the Supply Chain division have long histories at Raytheon (or General Motors before that or Hughes Aircraft Company before that) and remain unconvinced of the value of lean concepts. As a result, Supply Chain is often an obstacle in creating effective lean production systems.

While Supply Chain has a questionable reputation throughout the company, Supply Chain is very important to SSM operations. As the organization is currently structured, Supply Chain (P&IC and warehousing together) is responsible for releasing parts to the manufacturing floor. Because the various project managers have varying opinions on which parts should be a priority, these project managers sometimes spend a great deal of time working with P&IC, warehousing, and SSM Operations management to sort out reasonable allocation of time and resources on the floor.

7.4 General Culture at Raytheon

Stated broadly, the culture at Raytheon is defined by its technical excellence and commitment to providing the best products to customers in the armed forces and government. What is now Raytheon SAS in El Segundo, which was owned briefly by General Motors, actual began its life as Hughes Aircraft Company, a not-for-profit research center and manufacturer. Hughes was very clearly focused on developing incredible technologies for use by the U.S. government and was only peripherally concerned with profitability. Such a culture was superior for encouraging innovation and invention, but this culture also marginalized the value of operations and an efficient supply chain. Because a large percentage of current Raytheon employees began their careers at Hughes, the Hughes culture still remains in various pockets of Raytheon. This fairly complicated past results in a diverse company with several distinct cultures.

The division between management and labor is often contentious and has precipitated union-led strikes in the past. Conversations with unionized operators and stock clerks as well as managers confirm that there still exists a great deal of mistrust on both sides. Several stock clerks angrily voiced disapproval of the management styles of their supervisors, stating that they were "treated like bad children." Not surprisingly, several supervisors made the same analogies, stating that the stock clerks and operators acted like children and needed to be disciplined accordingly. This type of relationship between management and operators can make a lean implementation difficult. First, when operators and stock clerks do not trust that management is acting with the best of intentions, it is difficult to convince these operators to embrace a different way of doing work. These operators naturally fear that they will "lean themselves out of a job." At the same time it is often difficult to convince managers to empower employees and entrust operators to make decisions previously only made by managers. Without the ability to empower operators and stock clerks, it is very difficult to reduce management overhead. Accordingly, managers too worry that they will "lean themselves out of a job."

Being a major defense contractor, Raytheon is normally asked to maintain confidentiality and to protect sensitive information. Maintaining such secrecy makes it difficult to maintain close relationships with suppliers and contract manufacturers. As a result, Raytheon has historically held contract manufacturers like Teledyne at arm's length, preferring to provide minimal technical information or demand forecasts. Raytheon has also historically asked for little information from companies like Teledyne.

7.5 General Culture at Teledyne

Teledyne is a contract manufacturer that is focused on efficient operations and manufacturing. For several years Teledyne has committed to training its employees in lean concepts and regularly utilizing these concepts. In line with a commitment to lean ideals, most pieces of equipment on the production floor at Teledyne can be moved easily – and often are. One supervisor stated that equipment is moved around so often that she had stopped noticing changes. As a result of the constant changes on the production floor, Teledyne operators seemed to be very comfortable with the changes made as a result of this project. As an example, one change in manufacturing flow at Teledyne involved the operators retrieving parts from a remote inventory at Teledyne instead of using Raytheon-supplied kits of parts. While the operators were hesitant to use the new system, within a few hours they had decided that the system was an improvement and modified the system slightly to make it even better. Teledyne appears to have a strong culture of change.

7.6 Discussion of Cultural Issues

As mentioned in Section 7.3, Solid State Microwave and Supply Chain are intimately tied together. As such, SSM will absolutely need to work with Supply Chain in order to improve product flow and reduce overall wastes. Through enhanced partnering Supply Chain has a significant opportunity to benefit from SSM's experience with implementing lean manufacturing flow. Projects similar to the project presented in this thesis offer opportunities for Supply Chain personnel to learn from lean "veterans" in the operational units they serve. In the future, as Supply Chain builds up its own troop of lean veterans, Supply Chain will have the opportunity to provide lean support for the various factories and labs throughout Raytheon.

Focusing specifically on the project presented in this thesis, it does appear that this project may face some problems regarding sustainability. Because the thrust of this project is to bring Teledyne closer to Raytheon and integrate manufacturing at the two companies, there is a natural tendency for Raytheon to resist this change. As previously described, Raytheon is not a company with a long history of successful outsourcing.

Instead, Raytheon has historically responded to through vertically integrating and building capabilities and capacity internally.

If Raytheon collectively commits to building up outsourced capacity and implements the structural recommendations presented in Section 6.7, Teledyne does offer Raytheon an exciting learning opportunity. Because of Teledyne's experience in other, non-defense industries, Raytheon would have an opportunity to learn from Teledyne's broad experiences and assemble applicable best practices for manufacturing. More importantly, closer interaction between Raytheon and Teledyne could expose Raytheon Supply Chain and operations personnel to Teledyne's flexible operations and culture of constant change.

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8 Thesis Summary

This thesis presented a case study on implementing a new, lean manufacturing system immediately following a disaster. Beginning with a description of the manufacturing system prior to July, 2004, it was apparent that existing processes were not optimal. An initial-state value-stream map of the manufacture of offload assemblies revealed that Raytheon was allocating scarce resources (stock clerks and managers) to tasks that were better suited to the operators at Teledyne, the contract manufacturer performing the final assembly of offload assemblies. Worse yet, the tasks of tracking a large variety of purchased parts at Raytheon and preparing kits of parts for Teledyne resulted in a substantially longer cycle time than was necessary.

Following the disaster in its substrate area, Raytheon dedicated itself to drastically reducing the cycle time on its offload assemblies. With this surge of energy and visibility, the stage was set for major changes to occur in the manufacture of offload assemblies. The prioritization of 90-dash subassemblies manufactured at Raytheon was reviewed and modified, resulting in smaller lot sizes and an enhanced service level. In parallel, the task of preparing individual kits of parts for final assembly at Teledyne was moved from Raytheon's storeroom to Teledyne. This offload of responsibility to Teledyne was accompanied by a small, remote inventory of Raytheon-supplied parts at Teledyne and a streamlined, error-proofed system for quickly retrieving parts. This remote inventory functioned as a "mini-market" where Teledyne operators could quickly gather all necessary parts with minimal waste. This remote inventory was then stocked once per month through "bulk kits" prepared by Raytheon and inspected by Teledyne. As a result of these changes, 17 hours of labor per week were eliminated from Raytheon's storeroom and Teledyne's total cycle-time was unaffected.

As the bulk kitting process stabilized, a "Pod" system was introduced to simplify manufacturing prioritization at Teledyne and to drive Raytheon to hold a higher percentage of "usable inventory" in finished offload assemblies. This Just-In-Time system also forced Raytheon and Teledyne to engage in more regular communications and to become more integrated partners.

Looking forward, the results presented in this thesis also reveal opportunities for Raytheon to further improve both its inventory management strategy and its procurement strategy. Given the successes associated with creating mini-markets at Teledyne, there may also be opportunities for Raytheon to attempt similar relationships with other suppliers as well as within Raytheon's internal manufacturing areas. Finally, the analysis of Raytheon's current inventory levels of purchased parts revealed high inventory values, extremely high carrying costs, and disappointingly low service levels due to high inventory levels of the wrong parts. The theoretical ABC inventory analysis presented in this thesis points to major cost savings that can be reaped through more strategic procurement decisions with a focus on the total cost of ownership of inventory.

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10. Chapman, Timothy, et al., "Purchasing: No Time for Lone Rangers," *The McKinsey Quarterly*, 1997, Number 2, pp. 30-40.

11. Raytheon's Supplier Managed Inventory (SMI) system is essentially identical to Vendor Managed Inventory (VMI) systems used widely in the manufacturing industry

12. www.impact21group.com/glossary.htm [Accessed April 15, 2005]

10 Acronyms

Conwip	Constant work in progress
DBV	Distribution by Value
EMI	Electromagnetic Interference
FIFO	First-in-first-out
MIC	Microwave integrated circuit
MRP	Material Resource Planning
P&IC	Production and Inventory Control
RF	Radio frequency
SAS	Space and Airborne Systems
SCM	Supply Chain Management
SSM	Solid State Microwave
WIP	Work in progress

Appendix A: Example of an Offload Assembly Priority List prepared by Raytheon for Teledyne

Dates Refer to Deliveries from Teledyne			Past Due	Due 10/8	Due 10/15	Due 10/22	Received from Teledyne Week of 10/1	Completed by Teledyne Week of 10/8					Shortage Notes
								Mon	Tues	Wed	Thurs	Fri	
Page 1	F-18 F-15 INT RCVR	5102245-006 & 5142930											
	A1 Common	5115174	41	53	65	72							Kit of 33 short 33 90-'s
	A2 Common	5102910	7	19	31	38	10						
	A3 Common	5102913	20	32	44	51	13	10					No Kits
	A8 Common	5115233	1	13	25	32	1	10					
	A5 Common	5142090		5	17	24	31						
	A6 Common	5142093		6	18	25	33	11					
	A9 Common	5102252-001		2	14	21	34	11					
	A10 F-15	5142940	19	31	43	50							Kit of 22 short 22 90-'s
	A10 F-18	5102255											
	Non-TEL	90-5102251											
	Non-TEL	91-5102247-001											
	Non-TEL	90-5102246-003											
Page 2	FMR CAL	5102890-020											
	A1	5102899			1	6	14						
	A2	5140241			1	6	14						
	A3	5102901-001		5	10	15	2	5					Kit of 7 short 7 90-'s
	A4	5102902-001		3	8	13							
	Non-TEL	91-5102890-010											
	Non-TEL	90-5102891-004											
Page 3	BIT MICRO	5102297-002											
	A1	5102311		2	5	6							
	A2	5102312			1	2		4					Kit of 7 short 3 90-'s
	A3	5102313		2	5	6	6						
	A4	5102314		3	6	7							
	A5	5102315											
	A6	5102316			1	2		3					Kit of 7 short 4 90-'s
	Non-TEL	91-5102297											
	Non-TEL	90-5102298-001											
Page 4	PWR AMP	5102860-003											
	A1	5102873	8	12	16	20							Kit of 21 short 21 90-'s
	A2	5102874			1	2							
	A3	5102875-001			3	4							
	A4	5142101		3	7	8							
	A5	5102877-001			2								
	A6	5102878											Kit of 28 short 14 90-'s
	A7	5102879		3	7	8							Kit of 7 short 7 90-'s
	A9	5102881-001		2	6	10		10					Short SSM1203
	A10	5102882	1	5	9	13		2					Kit of 7 short 5 90-'s
	A11	5102883-002			4	8							
	A12	5102885-002		2	6	10	5	7					Kit of 21 short 12 90-'s
	Non-TEL	90-5102880	18	22									
	Non-TEL	91-5102860											
	Non-TEL	90-5102861-001											
Page 5	PHASE MOD	5102833-002											
	A2	5102848				1							
	A4	5102850				2							
	A7	5102853		3	7	11		4					
	A8	5102854		2	6	10							
	Non-TEL	90-5102852											
	Non-TEL	91-5102833											
	Non-TEL	92-5102833											
	Non-TEL	90-5102834-001											
Page 6	TD UP	5102270-002											
	A7	5102294-001				8							
	Non-TEL	90-5102283											
	Non-TEL	90-5102287											
	Non-TEL	91-5102270											
	Non-TEL	92-5102270											
	Non-TEL	93-5102270											
	Non-TEL	90-5102295-001											
Page 7	LO DIST	5102750-002											
	A1	5102764-001		3	6	7		2					Kit of 21 short ~~18~~ 3 90's
	A2	5102765											
	A3	5102766					7						
	A6	5102768				-5		7					
	A12	5102777											

Appendix B: Process Flow Diagram for the Pod System